School of Engineering and Computing
Department of Civil Engineering

Hydraulic characteristics and performance of stormwater pollutant trap respect to weir's height, flow gradients, pipe diameters and pollutant capture

Hamid Khabbaz Saberi

This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University of Technology

June 2009

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: …………………………….

Date: ………………………….

LIST OF PUBLICATIONS

(1) "**Hydraulic Characteristics and Performance of a Stormwater Pollutant Trap**" *2nd Curtin Engineering Faculty Research Colloquium 2007 Perth Western Australia*

(2) "**Headloss/Flow Rate Relationship in a Scale Model Stormwater Pollutant Trap**" *8th International Water Association Specialized Conference on Small Water IWA 2007, Coimbatore India*

(3) "**Headloss/Flow Rate in a Stormwater Pollutant Trap and Hydraulic Characteristics of the Weir in a Diversion Weir Pit**" *1st International Conference on Advanced Wastewater Treatment and Reuse AWTR 2007, Bhopal India*

(4) "**Characteristics of Flow Rate, Headloss and basket Pressure Drop Relationship in a Rocla VersaTrap Stormwater Pollutant trap in a 3-D Laboratory Scale Model**" *9th International Conference of Modelling, Monitoring and Management of Water Pollution 2008, Alicante Spain*

(5) "**Experimental Approach to Investigate the Relationship between Weir Height and inlet Pipe Diameter**" *International Conference on Environment 2008, ICENVE Penang Malaysia*

(6) "**Laboratory Test Performance of a Gross Pollutant Trap**" *1st International Conference on "Advanced in Wastewater Treatment and Reuse" AWWTR 2009, Tehran Iran*

(7) "**Headloss/Flow Rate in a Stormwater Pollutant Trap and Hydraulic Characteristics of the Weir in a Diversion Weir Pit**" *Journal of the Environment Research and Development Volume 2 No. 4B April-June 2008*

(8) "**Characteristics of Flow Rate, Headloss and basket Pressure Drop Relationship in a Rocla VersaTrap Stormwater Pollutant trap in a 3-D Laboratory Scale Model**" WIT PRESS. (2008) "*WATER POLLUTION IX*," ed. C.A.B. D. Parts Rico, Y. Villacampa Esteve. 2008, Southampton, Boston: WIT PRESS. 639.

(9) "**Experimental Approach to Investigate the Relationship between Weir Height in a Divert Pit Trap"** World Applied Science Journal WASJ (in press)

ABSTRACT

The main focus of urban stormwater runoff disposal has traditionally been to provide structurally-sound drainage systems to carry runoff from many different surfaces without considering water quality at outfall. This has contributed to the decline of water quality in rivers and lakes and other receiving bodies. According to Lord (1987), “stormwater management is primarily concerned with limiting future flood damages and environmental impacts due to development, where as flood control aims at reducing the extent of flooding that occurs under current conditions”. Recent developments in stormwater pollutant trap (SPTs), which are generally end-of-the-line devices designed to capture and store gross pollutants, for subsequent removal and disposal.

During the last few decades, use of SPTs as a source of collecting and removing pollutants from stormwater (which carries many different types of chemicals and non-chemical pollutants that contaminates our rivers, lakes and other receiving bodies) has increased considerably. Wide-ranging efforts and attempts have been made in both academic and industrial research to improve the quality of stormwater by improving the use of gross pollutant traps (GPTs – known as hydrodynamic separators) by utilising and improving available experimental and modelling techniques. The use of vortex phenomena has always been a challenging problem and available data is rare and complicated in the literature. This research focuses on detailed investigation by experimental means. The generated vortex in this experiment is created in a cylindrical chamber above the level of a cylindrical screening basket. In addition, the research analyses the processes involved in this separation technique.

One scale model of a Versa Trap (Type A) was experimentally analysed to investigate and establish the relationship between headloss and flow rate and hydraulic characteristics of a weir in a diversion weir pit. The Versa trap Type A storm pollutant traps are usually used as off-line traps in city and urban areas to capture and store debris – especially those which are captured from surfaces such as rooftops, paved streets, highways, parking lots, lawns, and paved and gravelled roads (Allison *et al*., 1998). The Versa Trap Type A utilises an upstream diversion weir pit to divert the design treatment flow (DTF) into the treatment chamber. Treated flow returns to the diversion pit downstream of the weir,

where it re-enters the drainage system. Peak flow in excess of the DTF bypasses the SPT over the weir into the pipeline downstream.

It has been demonstrated that the aggregate of all flows of three months average recurrence interval (ARI) and less represented the majority (up to 97.5%) of the total flow generated by a stormwater drainage catchment (Works, 2006). There is some conjecture as to the veracity of the ‘first flush’ theory, which holds that most of the pollutants in the catchments are transported during the first flush of the storm event (Lee *et al*., 2007). However, it is generally accepted that SPTs should be sized so as to treat only a portion of the peak flow, with excess flows bypassing the trap. The three month ARI peak flow is commonly taken as appropriate for establishing the minimum DTF required of the SPT.

The measurement of headloss across a scale model of a VT Type A storm pollutant trap at a range of flow rates through the SPT, provide data from which a mathematical relationship between flow rate and the headloss cab be established for the device.

The resultant relationship then can be used in another part of the experiment to establish the hydraulic characteristics of a weir across a cylindrical chamber, as used for the upstream diversion weir pit in conjunction with the Type A VT range of SPTs. By varying the weir height in a scale model of a diversion weir pit and measuring the flow rates associated with headlosses determined from the previously established relationship, the relationship between weir height and diverted flow can be established. This allows the designer to specify the weir height required to divert the flow rate associated with a specific peak flow or treatment flow of SPT design.

Two main characteristics which determine the performance of a gross pollutant trap are trapping efficiency and required maintenance. The trapping efficiency is defined as the portion of the total mass of gross pollutant transported by stormwater that is retained by the trap. A low trapping efficiency means that gross pollutants pass through the trap and reach downstream waters. A poorly-maintained trap will be inefficient at trapping pollutants and is also a potential source of pollutants as trapped materials break down.

The experiment parts of this project were tested at Curtin University of Technology’s Hydraulic Laboratory. To replicate typical in-situ conditions, the VT Type A was tested

for 0, 22, 33, 44, 55, 66 and 77% simulated blocked screen conditions for trapping efficiency. Data analysis has demonstrated that the headloss increases in proportion to flow rates and screen blockage condition. The results were scaled up to provide data on the full range of unit sizes. This research describes the testing and scaling methodologies in detail, with graphical representation of headloss and other hydraulic parameters at various conditions. The study's findings have capabilities to optimise any other types of stormwater treatment systems. These types of traps' are used in commercial and residential environment.

This experiment is in continuation of the experiment which was conducted by Muhammad Ismail on industrial gross pollutant traps using double basket to trap the debris for industrial application.

Also another good reference for pollutant build up and wash off modelling of impervious surfaces in Perth area, is done by Saadat Ashraf in his PhD thesis. For more information refer to references.

ACKNOWLEDGMENT

I would like to express my gratitude to all of those who gave me the possibility to complete this thesis.

I thank my parents for everything they gave me and it is largely due to their efforts that started from early years of school, that I have achieved what I have.

I am deeply indebted to my supervisor Prof. Dr. H. Nikraz whose help, stimulating suggestions and encouragement helped me throughout the research and writing of this thesis.

I wish to thank my wife and two daughters for their support and sacrifices they had made during over the years.

I wish also to thank Johan Murray, head of the engineering laboratories and technicians – especially Michael Appleton, Ashley Hughes and Mark Whitaker for their continuous support and help whenever it was needed.

My especial thanks goes also to Dr Peerapong Jitsangiam for his kind and valuable help in preparing the final draft.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1. INTRODUCTION

Water is our most precious and valuable source of life which plays an essential rule in the life of the human being and other species living on Earth. The importance of water as a source of life is evident throughout the history of mankind. First civilisations established where the rivers and water resources were sited. With an increasing world population and increasing water usage for different purposes (mainly domestic, agricultural and industrial), and considering limited water resources remaining unchanged, unpolluted water demand has increased dramatically. Unfortunately because of the misuse of this valuable resource, water quality is decreasing due to different types and sources of pollution. Domestic and industrial usage of water generally produces deteriorations in water quality and generated wastewater should be treated effectively before being released into rivers, lakes and other receiving bodies. It is important to note that pollution reduction is a primary objective for managing stormwater runoff from low intensity rainfall events and ‘first flush’ storm events. For stormwater flows from high intensity rainfall events, the primary objective remains to reduce flooding of buildings, infrastructure and other assets. ‘First flush’ describes situations when pollutants (e.g. sediments) that have accumulated on impervious surfaces are transported at the beginning of a rainfall event. This results in high pollution concentrations at the start of the runoff hydrograph, reducing to lower levels before the flood peak occurs (Argue, 2004). Contaminants may be present as large suspended solids; small suspended and colloidal solids; dissolved organic and inorganic solids; solid gases; immiscible liquids; and heavy metals (Menezes *et al*., 1996).

1.2. DEFINITION OF GROSS POLLUTANTS

The term ‘gross pollutant’ is variously defined in the literature, but when used in connection with stormwater drainage systems, can include debris, litter, and sediments (Willing & Partners, 1992; Essery, 1994). Debris is defined as any organic material transported by stormwater (such as leaves, twigs and grass clippings) as defined by DLWC (1996). Litter is defined as human-derived material including paper, plastics, metals, glass and cloth (as defined in the Litter Act, 1987). Sediments may be defined as inorganic particulates.

There is little reference in the literature as to the minimum size of material that is considered a gross pollutant. For the purpose of this thesis, gross pollutants are defined as *material that would be retained by a five-millimetre mesh screen***.** This definition is used for two reasons: firstly, to emphasise the impact of litter and debris (as opposed to sediments) on receiving waters and secondly, this definition is consistent with the five-millimetre screen size of gross pollutant trap tested as part of this thesis.

Stormwater can transport and deliver large quantities of pollutants to receiving water-ways. These pollutants can endanger receiving water and impair the nominated beneficial users. Gross pollutants (material larger than five millimetre) make up a considerable volume of the pollutants and mass of the total solids transported (Allison, 1999). Gross pollutant mainly includes paper, plastics and natural debris is a threat to wildlife and aquatic habitats, look unpleasant, smell and attract rodents. Their presence in waterways is the public's number one concern and indicator of waterway health. The majority of material monitored by Allison in Australian waterways was vegetation (typically 70 percent by mass), with plastics and paper discarded from pedestrian and motorist activities making up most of the remainder. A detailed item discovered was that two-thirds of litter items were from cigarettes and their packing. The CRC monitoring also sampled gross pollutant loads from different land use types and found that commercial concerns such as shopping centres and fast food outlets were the largest contributors of litter (Allison, 1999).

Although environmental problems associated with gross pollutants in urban waterways are recognised, there has been little research in Australia into gross pollutant characteristics and movement (Allison, 1997). There is also limited information available on the performance of structural devices to trap gross pollutants.

The quality of the stormwater depends on five natural processes. These processes that affect the movement and transformation of pollutant in an urban catchment are:

Chemical processes – those which involve the reaction of two or more compounds with each other to form one or more different compounds. An example of a chemical process in a natural system is the transformation of SO2 into SO3 and eventually, H2SO4 (sulphuric acid) in the atmosphere.

Biochemical processes – those which are the result of chemical transformation taking place within a biological organism, such as bacterial decomposition of organic material and photosynthesis.

Physio-chemical processes – those which involve chemistry and physics of molecules interacting with their surroundings. Three of the most important physio-chemical processes are *adsorption*, *desorption* and *absorption*. *Adsorption* is the adhesion of a substance to a surface of a solid or liquid. This is an important process because many pollutants such as nitrogen, phosphorous, various pesticides and heavy metals attach themselves to sediment particles and are in turn transported with the particles in the flowing water. The quantities of pollutants that become attached to sediment particles are a function of concentration of pollutants in the runoff and, temperature. *Desorption* is the release of the pollutants from sediment particles. *Absorption* is the penetration of a substance into or through another. It usually takes place at the air-water interface where gases are absorbed into the water. This is the primary mechanism whereby receiving water bodies obtain oxygen.

Ecological processes – those which involve interactions between different organisms in the food chain. This includes consumption, growth, mortality and respiration from organisms. Transport or physical processes describe the movement of pollutants by fluid motion. This is primarily by the action of advection, by fluid movment and diffusion, by the motion of the molecules and by turbulent fluctuations in the fluid dispersing material. The transport process acts independently of the transformations of non-conservative substances and is equally valid for both conservative and non-conservative substances. The materials that are not transformed chemically while being transported are termed *conservative substances*, otherwise they are *non-conservative substances*. For example, dissolved salts are conservative because, generally, they do not interact with other substances. Nitrogen, in its ionic state, will undergo chemical, physio-chemical and biological transformation in a water body (CSIRO, 1999) and therefore, is considered to be non-conservative.

Physical processes – those which depend on the physical properties of the stormwater such as particulate size and the specific gravity. These include screening, sedimentation and filtration.

The quality of the water in stormwater systems is mainly affected by; biological effect, salinity, toxic substances, temperature, dissolved oxygen and sedimentation. The effect of temperature arises in; physiochemical reactions, biochemical reactions, biological process and the behavioural pattern of organisms. Temperature effects can also be seen in synergistic effects – i.e. higher water temperatures exacerbate the adverse effects of low dissolved-oxygen concentrations. Salinity problems are related to high concentrations of total dissolved salts. Salinity levels affect aquatic organisms as well as uses of water withdrawn from receiving water. Sedimentation is a natural process, which has been accelerated in many places by man's conduct. Suspended sediments in high concentrations lessen light penetration, thereby inhibiting photosynthesis by aquatic organisms. Sediments that are deposited can smother plants and organisms and destroy fish spawning grounds. Sediments entering waters can also carry attached nutrients, pesticides and heavy metals. They also clog water treatment plant filters, as well as blocking channels and pipes. Dissolved oxygen is important as an indicator of water quality. Organisms in aquatic systems must have oxygen to be able to live. The primary demand for oxygen in receiving water bodies is by decomposing organic material. The three indicators which are used in relation to oxygen demands are; biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC). *BOD is a measure of the total amount of oxygen required to biochemically oxidise organic matter at a specific temperature and time. It is generally considered a major indicator of a healthy water body.* COD and TOC are indicators of the total amount of the available organic material. Toxic substances include; herbicides, pesticides, heavy metals, radioactive materials, oils and reduced ions. The sources, health and environmental consequences of variety of pollutants that can be available in urban stormwater are given in Table 1 as it has been indicated in CSIRO Land and Water Technical Report No. 52/99 (December 1999).

Table 1-1 Health and Environmental Consequences of Various Contaminants

Contaminant	Sources, Health and Environmental Consequences
Nitrogen	Amongst the major point sources of nitrogen in water bodies are municipal and industrial wastewater and septic tanks. Diffuse sources of nitrogen include fertilisers, animal wastes, leachate from landfill and atmospheric fallout. Nitrates become toxic only under conditions in which they are reduced to nitric. In high concentrations nitric is known to cause methemoglobinemia in bottle-fed infants.
Phosphorous	In the elemental form, phosphorous is highly toxic. Phosphorous as phosphate is one of the major nutrients required by plants. Phosphorous is not the sole cause of eutrophication, but it is a limited factor for aquatic plants. Phosphates enter waterways from different sources. These include human and animal excreta, surface runoff, and atmospheric fallout. High concentrations of total phosphate may interface in water treatment plants. Algae growth imparts indescribable tastes and odours to water, interfaces with water treatment and becomes aesthetically unpleasant.
Copper	Prolonged excessive quantities of copper may result in liver and kidney damage. Copper may impart some taste to water. Toxicity of copper to aquatic life is dependent on alkalinity. The lower the alkalinity, the more toxic copper is to aquatic life. It is rapidly absorbed in sediments. It is highly toxic to most aquatic plants as well as most freshwater and marine environments. It is considered more toxic to freshwater fish than any other heavy metal except mercury. Major sources of copper occur in; steel production, sewage treatment plant wastes, and corrosion of brass and copper pipes. It is used in electrical wiring, plumbing and the automobile industry. Copper sulfate has been widely used in the control of algae in water supplies.
Coliforms	Coliforms are an indicator organism for facial coliform, streptococcal and other pathogenic bacteria. Sewage and animal waste are major sources of coliform bacteria. Possible chronic health effects of coliform bacteria include; gastroenteritis, salmonella infection, dysentery, typhoid fever and cholera.
Chromium	Chromium was used in making paint pigment, toxic colouring and tanning. More recently, it is used in production of stainless steel, photoelectric cells and ceramic glazes. The principal emissions of chromium into surface waters come from electroplating, waste incineration, contaminated laundry detergent and bleaches, and septic systems. Toxicity of chromium to human and aquatic organisms is generally low. Under most conditions, mercury, cadmium and copper are more toxic than chromium. Soluble compounds can cause liver, kidney and lung damage.
Cadmium	Cadmium is toxic to man, causing chronic disease. It is deposited and accumulates in various human body tissues. Its major source is industrial production involving such as; electroplating, pigments, plastic stabilisers, discarded batteries, paints, corrosion of galvanised pipe, fertilisers and sewage sludge. In aquatic systems, it is adsorbed into sediment particles. Certain invertebrates and fish are very sensitive to cadmium.
Iron	Pollution sources of iron are industrial waste, iron-bearing groundwater and leaching from cast iron pipes in water reticulation systems. In the presence of dissolved oxygen, iron will precipitate as a hydroxide, forming gels or flocs. These may be detrimental to fish and other aquatic life as they settle over streambeds smothering invertebrates, plants and spawning grounds. In water supplies, it affects taste and stains clothes and plumbing fixtures. Only low concentrations of iron are required for this.
Lead	Lead is used in storage batteries, pipes, paints, petrol additives, solder and fusible alloys. Combustion of oil and petrol is the major source of lead absorbed by humans. Lead enters the aquatic environment through: precipitation, leaching of soil, street and municipal runoff, corrosion of lead pipes, discarded storage batteries, lead-soldered pipe joints and industrial waste discharges. It is a toxic metastatic accumulated in the tissue of the organisms by ingestion or inhalation of dust or fumes. It results in irreversible nerve and brain damage in infants. Kidney damage, blood disorders and hypertension are symptoms of health problems associated with lead. The major toxic effects of lead include anaemia, neurological dysfunction and renal impairment. Lead is less toxic to invertebrates than copper, cadmium, zinc and mercury.
Mercury	Mercury is very toxic to aquatic plants, organisms and humans. It can accumulate by: ingestion, skin absorption and inhalation of vapour. Long-term exposure can produce brain, nerve and kidney damage. Birth defect and skin rash have also been attributed to exposure to mercury. Sources of mercury include: amalgams, electrical equipment, fungicides, mirror coatings and sewage. In the aquatic environment, mercury is associated with suspended solids.
Suspended solids	For aquatic life, suspended solids can reduce light penetration, which will adversely affect photosynthetic activity. Suspended sediments provide areas where micro-organisms do not come into contact with chlorine disinfectant and so influence the efficiency of water treatment processes.
Zinc	An essential element in human metabolism, however it has a bitter taste. Toxic concentrations of zinc components cause adverse damage to the morphology and physiology of fish. Mercury and copper are more toxic to fish than zinc. Mercury and zinc are more toxic to aquatic plants and invertebrates than zinc. The rare toxicity of zinc arises from its synergistic interaction with other heavy metals.

1.3. VORTICITY

In this project, the vortex technique is studied as the physical separation process for removing pollutants from waste/stormwater. Rocla Versa traps are designed to use vortex phenomena to remove pollutants over a wide range of flow rates.

An important concept unique to water flow especially in fluid dynamics is vorticity. It can be thought of as an analogy of rigid body rotation, in a non-rigid medium. If we could suddenly freeze a very small portion of fluid, it would spin with an angular velocity that would be a local vorticity. Vorticity is a vector; thus we can have vortex tubes defined analogously to stream surfaces and stream tubes. An example of vorticity is shown in Figure 1.1 below. This photo was taken during the first part of the experiment. There are many different tests which can show the formation of the vortex phenomena in many different situations. Vortices are the principal features of turbulent flow.

Figure 1.1 Vortex Phenomena in Stormwater Pollutant Trap of Experiment

1.4. GROSS POLLUTANTS - SIGNIFICANCE AND INNOVATION

Gross pollutants can foul the engines of small to medium size craft and cause significant cost to the marine environment. The Maritime Services Board (NSW) spends \$1.3 million per year on harbour cleaning of gross pollutants (Sydney Harbour Task Force, 1991) and each year, Melbourne Water allocates \$1 million to litter management reduction (Collette *et al*., 1993). One of the major ways of controlling sediments and pollutants in waste and stormwater is the use of a pollutant trap. In this experiment, with use of an off-line Storm Pollutant Trap (SPT) and entrapment basket of 5 mm aperture, we capture and entrap sediments larger than 5 mm in diameter. The innovation used in this research is to develop a vortex separation model of a SPT to trap small particle size sediments which are usually carried away by debris from runoff water of surfaces such as rooftops, paved streets, highways, parking lots, lawns, and paved and gravelled roads (Armitage *et al*., 1998). The entrapped debris through this type of SPT is shown in Figure 1.2 (from the Stormwater Gross Pollutant Trap Industry Report page 1) below. Since there are different ranges of the sediment particles associated in storm pollutants, the main focus of this study is only on physical removal of the particles and any other type of treatment – i.e., chemical or biological treatment of the pollutant – is not considered in this scope of the study. Although understanding that stormwater management involves a wide range of treatments, it is not possible to consider, in any one single study, all the many concepts and processes

Figure 1.2 Stormwater Gross Pollutants

1.5. FLOW PROPERTIES AND CHARACTERISTICS

In studying the flow of fluids, we encounter a wide variety of distinct ways in which the flow may be characterised. Many times the terminology used is of an either/or nature; that is, a flow is steady or unsteady, laminar or turbulent, uniform or non-uniform. In many applications the boundaries between the various classifications can be imprecise, and when we do use these broad categories, they may apply only to a portion of flow region, rather than to the entire flow region. As in most tasks in engineering, simplified models are always the starting point for the analysis of a problem (Graebel, 1999).

Increasing concern about the quality of the gross pollutants in urban waterways is leading to greater use of gross pollutant trapping devices. Although different types of trapping devices are now available, there is little information on their performance. Basically two main characteristics determine the performance of a gross pollutant trap – trapping efficiency and maintenance requirements. The former is considered the prime consideration in this study. The trapping efficiency is defined as the portion of the total mass of gross pollutants transported by stormwater that is retained by the trap. A low trapping efficiency means that gross pollutants pass through the trap and reach downstream waters. A poorly-maintained trap will be inefficient in trapping pollutants, and is also a potential source of pollutants as trapped materials break down.

The efficiency of pollutant removal by a gross pollutant trap (GPT) is one of the major considerations when selecting a SPT for a specific condition. One main consideration when installing a SPT in a drainage system is headloss. This matter should be very well examined during the design process. For this reason, the pollutant removal efficiency and hydraulic characteristics of this type of trap are experimentally investigated in detail.

This research intends to develop a model with the vortex separation method which can be used to segregate pollutants from stormwater and hence, improve the quality of the water which is delivered to the receiving bodies. To achieve this, the following issues are considered:

- Complete understanding of the energy equation in different forms

- Fair understanding and ability to convert different forms of energy from one state to others
- An understanding of vortex phenomena and its application in particle separation
- Cost issues in the production of SPTs in the stormwater treatment process
- The model calibration and validation are conducted in a laboratory environment using numerical simulation

This research is subdivided into the following three phases;

1.5.1. PHASE ONE: EXPERIMENT REVIEW

In order to have a better understanding of the vortex phenomena in the experiments relating the SPT to vortex phenomena, a literature review is conducted on GPTs and their modelling. Literature is studied on pollutant removal using the vortex application, on cost and benefit ratios of GPTs in water treatment, and finally, on validation and calibration of models used.

Stormwater modelling can be categorised in many different ways. According to Nix (1994), there are three categories of stormwater quantity estimation. These are (i) simple, (ii) simple routing and (iii) complex models. Each category has different demands on data and computing resources and provides results at different time scales and spatial resolutions. If flow is not modelled adequately, then water quality predictions will not reflect the true behaviour of the catchment.

1.5.1.1. STATISTICAL AND EMPIRICAL MODES

Statistical models that have been used for estimating stormwater flows and water quality loads are usually based on regression models. The related measured quantities such as physical parameters and water flows are important in a particular process. Regression modelling is an example of stochastic modelling approach – which may include climate characteristics of the region (such as rainfall intensity) and catchment parameters such as impervious area, land-use and catchment slope. The most important limitation of statistical models is that the statistical relationship developed from a given set of data reflects a particular spatial arrangement. For any distinctly different spatial patterns and processes, new data and new statistical relationships must be developed. Because of these limitations, the statistical approach has been primarily used only for crude analysis or in situations where deterministic approaches cannot be used because of insufficient data or resources.

An example of regression is the method for analysing runoff based on the antecedent precipitation index (API). It is the most frequently used and most important explanatory variable in surface water runoff. API is essentially the summation of the precipitation amounts occurring prior to the storm, weighted according to the time of occurrence.

Empirical models involve a functional relationship between a dependent variable and variables that are considered germane to the process. These variables are chosen from knowledge of physical process involved and from empirical measurements. An example of an empirical approach for estimating runoff is the rational formula

$$Q = CiA \tag{1.1}$$

The rational method is the simplest approach to modelling peak runoff volumes, which are important for stormwater infrastructural design. The rational method is a simple relationship between flow Q, the catchment area A, the rainfall intensity i, and a runoff coefficient C; where $0 \leq C \leq 1$.

1.5.1.2.DETERMINISTIC MODELS

Deterministic models are based on conservation laws, which govern the behaviour of the fluid. These laws generally involve the conservation of fluid, known as *continuity* and the conservation of momentum, known as *conservation of energy*. In almost all cases, one dimensional flow analysis is undertaken. Deterministic models used in stormwater modelling can be classified as either *hydrological* or *hydraulic* models.

Hydrologic models usually satisfy the continuity equation only.

Hydraulic models solve the continuity equation as well as either momentum or the energy equations as a coupled system equation. The major difference between these modelling approaches is that hydraulic models describe the spatial behaviour of a process. It is the momentum equation that defines the speed at which a process can occur.

Many engineers in Australia do not make this distinction between hydrology and hydraulic that is determined by the modelling process. For example, the rainfall-runoff process is considered as a hydrological process and flow in the open channels is considered a hydraulic problem. This distinction is due to the historical development of models used to simulate overland and open channel flows.

Computer models have been used to simulate the behaviour of aquatic systems since the mid-1960s (for example, the Stanford Watershed Model, Crawford & Lindsey, 1966).

Models to simulate stormwater quality and quantity appeared in the early 1970s and were developed mainly by US governmental agencies, such as the EPA. Other models have been developed since, from very simple conceptual models to complex hydraulic models.

In computer modelling, mathematical relationships that represent the behaviour of a system are solved by computer. In this type of modelling any variables in the model are considered as random variables having a probability distribution. So this type of model is called *stochastic* model. Otherwise the model is considered *deterministic* (Clark, 1973). In a deterministic model, all the variables are known with a certain degree; therefore the model will always produce identical results for the same input parameters. The advantage of stochastic model is that the uncertainty in a variable, defined by its distribution, is interwoven into the model. Unfortunately, to solve the stochastic equations, the random variables are restricted to certain probability distributions and for large problems, the solution of the stochastic equations are not practical (Li & McLaughlin, 1991). Reliability techniques are available for estimating the uncertainties in a model response due to random inputs (Thoft-Christensen & Baker, 1982).

Both stochastic and deterministic models may be further classified into two other categories known as *conceptual* and *empirical* depending on whether the model is based on physical laws or not.

Distributed and lumped models are also terms used to classify models. These describe how the model treats spatial variability. A lumped model takes no account of the spatial distribution of the input, whereas distributed models include spatial variability. “Most of the urban runoff models are deterministic-distributed models”, (Nix, 1994).

Catchment models can be further classified as either *event* or *continuous process* driven. Event models are used for simulating a few or individual storm events while continuous models simulate a catchments' overall water balance over a long period of time, involving monthly or seasonal predictions, and form the basis of *planning models* for water resources.

Experiment review is conducted to understand the energy equation in different formats and the ability to convert different types of energy together, plus to gain a good understanding of the total energy and specific energy line and vortex phenomena in GPTs. In the modelling we use vortex phenomena to remove pollutants. The cost and benefits associated in the design of GPTs in stormwater treatment is also reviewed and finally, the validation and calibration of the models are assessed.

1.5.2. PHASE TWO: THE CONCEPTIONAL PHENOMENA MODEL

A vortex (pl. vortices) is a spinning, often turbulent, flow of fluid. Any spiral motion with closed streamlines is vortex flow. The motion of the fluid swirling rapidly around a centre is called a vortex. The speed and rate of rotation of the fluid are greatest at the centre, and decrease progressively with distance from the centre. Vortex is basically a mathematical concept used in fluid mechanics. It can be divided in two categories; a) circular flow, b) rotary flow. It is related to the amount of the circulation or rotation in a fluid. In fluid dynamics, vorticity is defined as the circulation per unit area at points in the flow field. It is a vector quantity whose direction is along the axis of the swirl. Solenoidal or vortical flow in fluid dynamics is defined as vortical flow if the flow moves around in a circle or a helix, or tends to spin around some axis. The fluid pressure in a vortex is lowest in the centre where the speed is greatest, and rises progressively with distance from the centre. This is in accordance with Bernoulli's Principle.

Figure 1.3 Vortex Created by the Passage of an Aircraft Wing, revealed by Colored smoke

There are two major components in vortex phenomena, mainly velocity and pressure (Calvert, 2007). Two regions of vortex are shown on Figure 1.4.; the rotational region where the fluid rotates rigidly and its velocity increases linearly with radius of the circle, r, and the irrotational region in which velocity decreases inversely proportionally to r. Since area (A) is known, the velocity at any point can be calculated from its derivatives.

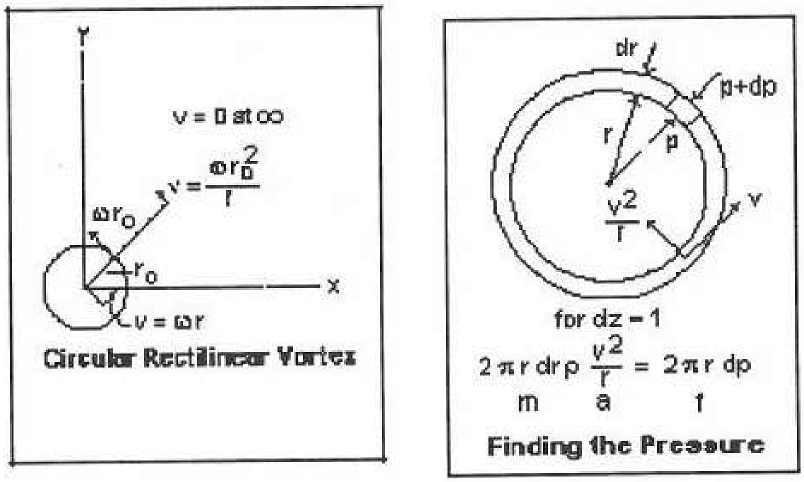


Figure 1.4 (a) Circular Rectilinear Vortex (b) Finding the Pressure

For finding the pressure, it is required to equate the centripetal acceleration to the pressure force: $-\rho v^2/r = -dp/dr$. Figure (1.4.b) shows that this equation can be easily evaluated from the first principles and Newton's Law, F = ma. The above differential equation can be easily integrated in the two regions of the vortex. In the irrotational region $P = P_\infty - (\rho/2)(v_o r_o/r)^2$, where P_∞ is the pressure at infinity, ρ is about 1.1 kg/m^3, v_o initial velocity and r_o is the radius. In the core of vortex, we find $dp/dr = \rho\omega^2 r$, where ω is angular velocity. When this is integrated, and the constant of the integration chosen to make the pressure equal at the surface of the core, we find $p = p_\infty - \rho v_o^2 + \rho v^2 + \rho v^2/2$. The pressure may fall to zero before the origin is reached. In this case, an empty ‘eye’ is produced that extends from the origin out to this radius. This project tends to apply the aforementioned concept for separation of the debris and pollutant from wastewater before delivering it to a receiving body.

1.5.3. PHASE THREE: SCALE MODEL TESTING

In this research a type of gross pollutant trap (called a Versa trap) is used in the research to develop the conceptional model and tested experimentally. Rocla pipeline sponsored the Versa trap Type A for this research.

Model Type	Scale
Rocla Versa Trap Type A (GPT)	1:2.5

1.6. RESEARCH OBJECTIVES

The main objective of this experimental research is to apply the centrifugal force (due to tangential connection of pipe to inner cylinder) created by differential pressure heads as a result of height difference of the inlet and outlet pipe flows for separation of pollutants to common off-line storm pollutant trap. The expected results of the experiment at conclusion should be as follows:

- To provide experimental data and information regarding the relationship between blockage of baskets due to gross pollutant movement, extensive flooding and stormwater pollution in drainage systems

- To establish the relationship between the basket trapping efficiency of GPTs and the pollutant load distribution trapped by different blocking percentage basket traps

- To outline the concept and criteria related to proposed design of engineered gross pollutant traps

- To propose a cost-effective gross pollutant trap for water quality and quantity problems

1.7. THESIS OUTLINE

The remaining chapters of this thesis are now outlined:

Chapter Two reveals a review of the literature related to the type of pollutants found in urban stormwater. The pollutant types and their percentages are first discussed in detail, and then the treatment methods and required devices for the type of treatment are looked at. The advantages and disadvantages of each treatment method with alternatives relevant to the objectives of this study are then presented.

Chapter Three reviews and investigates the dimensional analysis method and similarity for a VersaTrap model. The knowledge of hydraulic similarity is essential for design of a proper hydraulic model. The net force or driving force acting on the liquid flowing in a VersaTrap are proved. The efficiency and the headloss that depend on the related factors are also considered.

Chapter Four looks at the physical model design of VersaTrap. In this chapter the detailed explanations of operation, design treatment flow and peak flow for the model are provided. This chapter also provides the modifications and the specifications that Rocla Pipeline has done to improve the trap efficiency. This chapter also details the installation and maintenance costs.

Chapter Five presents the experimental process and methodology. The actual field conditions and the simulation method used for laboratory testing is shown and explained in this chapter. The hydraulic characteristics and the pollutant removal efficiency of the VersaTrap is explained in more detail in this chapter.

Chapter Six presents the experimental results using the VersaTrap model. The relationship of the headloss and headloss coefficient with the flow rates in each configuration are investigated. Then, the scaled-up results of the hydraulic characteristics (i.e. headloss) are revealed. The pollutant removal efficiency of the model is then detailed.

Chapter Seven presents the conclusions and recommendations of the study and identifies areas for future research.

Chapter Eight contains the References.

Finally, there are various Appendices collected from different sources and references to conclude the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1. STORMWATER POLLUTANTS

Stormwater is not as harmless as one might think. Several studies show that it contains considerable amounts of both nutrients and metals (Hived-Jacobsen *et al*., 1994). The physical, chemical and biological changes that result from land development often have adverse environmental impacts, such as increased incidences of flooding due to reduced rainfall infiltration and deterioration of water quality (Arnold & Gibbons, 1996). Moreover, the process of land use/cover conversion itself, particularly the removal of vegetation and disturbance of large areas of soil, can also adversely affect the aquatic environment. Numerous studies have shown sediment concentrations and loadings in stormwater runoff from uncontrolled construction sites to be significantly greater compared to sites with erosion prevention and sediment controls (USEPA, 2000a). Furthermore, deposition of sediment from these sites over short periods of time can exceed natural sediment deposition over several decades (USEPA, 2000b). Sediment-laden stormwater runoff from construction sites can overwhelm a small stream channel's capacity, resulting in streambed scour, stream bank erosion, destruction of near-stream vegetative cover, and loss of in-stream habitat for fish and other aquatic species (USEPA, 2000a). Catchment management authorities and local municipalities in Australia are undertaking a major public awareness campaign to reduce the gross pollutant problem and to encourage environmental awareness of the effects of urban community behaviour (Walker et al., 1999). Stormwater runoff contains different types and forms of pollutants, which cause impairments in the waterways. The stormwater contaminants can be grouped according to their water quality impacts such as solids, nutrients, biochemical oxygen demand (BOD) and chemical oxygen demand (COD), organics, trace metals, litter, oil and surfactants (Wong, 1997). Gross pollutants including sediments and litter are often targeted as the first group of stormwater pollutants in urban catchment management for water quality improvement (Walker *et al*., 1999). Oil and surfactants are also identified as a primary concern because of their visual impacts (Wong, 1997). All urban stormwater transports impact urban receiving waters and therefore require management. There is a variety of stormwater management strategies and methods that can be implemented by local authorities to protect their receiving waters. These include sweeping, infiltration trenches, detention basins, retention basins, vegetated swales, wetlands and gross pollutant traps which can reduce pollutants before they enter the surface water.

2.2. STORMWATER POLLUTANT SOURCES

The nationwide significance of pollution caused by storm-generated discharges was first identified in a United States Public Health Service report published in 1964 (Field, 1975). Congress recognised this as a problem and authorised funds under the federal Water Pollution Control Act of 1965 for research, development and demonstration of techniques to investigate the problem and implant the solution for controlling stormwater pollution.

Every year, billions of litres of stormwater flow down drains and into our rivers and creeks – most of these stormwater has polluted. Pollutant sources in Australia are similar to those observed elsewhere in the world. The major sources of the pollutants are litters, pathogens, toxicants, nutrients and suspended solids. Most of the studies in urban stormwater pollution have been carried out in the U.S.A. and Europe. (Mudgway *et al*., 1997) reported that the sources of pollution in Victoria (Australia) are not going to be much different to those in western countries. Pollutant sources in stormwater arise from various locations such as construction sites, urban areas and agricultural lands. The urban environmental causes significant changes to water movement by modifying the catchment and the waterway surfaces and increasing the concentration of stream flow and erosive power. The introduction of impervious surfaces of various forms prevents infiltration and provides a ready supply of introduced compounds. The remaining original surfaces can also be significantly changed by the land development process, which disturbs vegetation and exposes the soil surface (Settle *et al*.).

2.2.1. POINT SOURCES

Mainly there are two types of pollutants that can be responsible for pollution of stormwater. These are point sources pollutants and non-point sources of pollutants. Point sources of stormwater pollution can be pinpointed and shown to be directly responsible for a source of pollution. They are generally industries or intensive agriculture where discharge can be traced back to the specific area (Kidcaff, 2006). Point sources pollution is typically thought of as causing surface water pollution. Due to more stringent regulation of these point sources of pollution, their contribution to water pollution has greatly diminished (Peluso *et al*., 2002).

2.2.2. NON-POINT SOURCES

One of the major sources of the pollution and at the same time difficult to control in the waterways is caused by ‘non-point source’ pollution, as opposed to ‘point source’ pollution. Non-point sources of pollution can sometimes contribute more pollution in comparison to point source pollution (Peluso *et al*., 2002). “NPS of stormwater pollution are those which can possibly come from the large number of areas being non-specific”, (Kidcaff,, 2006). “It results from the accumulation of contaminants from land surface, erosion of soils, debris, increased volumes of stormwater runoff, atmospheric deposition, suspended sediments, dissolved contaminants and other anthropomorphic contaminants. It is sometimes difficult to differentiate between a non-point source and a collection of many smaller point sources”, (Peluso *et al*., 2002).

As indicated in Environment Australia 2002, stormwater can be treated as a resource that could bring environmental, economic and social benefits to our urban areas. Rather than going to waste and causing pollution; through capture, treatment and reuse, stormwater can become a major alternative to damming more rivers to ensure water supply. The strategies and methods of this potential resource mainly focus on the sources of runoff and pollution and the tools to control and reuse this water within urban housing, commercial and industrial areas.

2.3. THE PROCESS OF POLLUTANT TRANSPORT

There are mainly two ways that urban runoff is responsible for pollutant transport:

- Surface paths, usually during storm events
- Subsurface paths, generally continuous but often insignificant

According to Walker *et al*. (1999) there are many factors which influence the amount of stormwater and contaminations during pollutant transportation as follows:

- Duration and intensity of the rainfall

- Proportion of impervious surfaces
- Shape of the land
- Land use
- Design and management of the stormwater

2.3.1. BUILD-UP AND WASH-OFF

Urban stormwater pollution is produced by many different sources such as wet and dry deposition, importing pollutants in liquid, solid and gaseous forms. Some pollutants are stored permanently and others temporarily in the urban catchment, and this is called build-up. Build-up generally increases over time as the stormwater flows through the system. However, rates vary between land use, intensity of the storm and pollutant types. Rates of build-up and resultant loads have been found to be higher for commercial areas than for industrial areas (Mudgway et al., 1997).

Much research has found that build-up is concentrated near road kerbs and is also greater where the kerbs are higher. This suggests that dry weather removal (to adjust pervious and impervious areas) occurs due to disturbance and transfer by traffic and wind. The rate of removal by dry weather disturbance depends on whether pollutants can move back from the adjoining areas onto the surface. Increasing build-up is expected with increasing anticipated dry periods, however the shape of the curve cannot be accurately determined. Novony (1995) suggested a build-up function of the form:

$$\frac{dP}{dt} = I - kP \qquad (2.1)$$

Or in analytical form

$$P(t) = \frac{I(I - e^{-kt})}{k + P(0)e^{-kt}} \qquad (2.2)$$

Where

P(0) = initial load per unit kerb length (kg/m)

P(t) = load per unit kerb length (kg/m) at time t

I = input of particulate matter by dry deposition per unit kerb length (kg/m/day)
k = coefficient representing re-suspension and removal (l/day), about 0.2 to 0.4/day (i.e. 20–40 % of solids are removed daily).

The process where mobilisation and transport of pollutant from a surface like a roof or a street by rain is called wash-off. Generally wash-off from impervious areas is greater than from pervious areas, due to greater runoff volume, (e.g. surface detention can be up to four times greater on pervious surfaces than impervious surfaces) (Duncan, 1995b). It has been found in many research studies that the total built-up load is less than the wash-up load in any one rainfall event, indicating that some pollutant load is retained on the surface after rainfall. It has also been reported that the surface pollutant load decreases significantly only after a succession of high intensity rainfall events (Duncan, 1995b). Thus, the quality of surface runoff can be related to the quality of contaminants accumulated on surfaces and by erosion by rainfall depending upon the area where the experiments are conducted.

The magnitude and timing of first flush depends on the size of the catchments, the proportion of impervious area and the time of concentration on the catchments. Higher rainfall intensity tends to increase the magnitude and lead time of the first flush. The first flush effect has been observed in catchments in Melbourne by GHD & EPA (1981) and Moodi (1979), especially with particulate material where the size of the initial flush depended on rainfall intensity and size of the catchments.

2.3.2. TRANSPORT

During any storm event, depending on the intensity and duration of the event, the concentrated flow carries suspended solids, dissolved matter and gross pollutants. Some pollutants are particulate in nature and others can become attached to sediments during wash-off or transport, or adsorb to each other to form larger flocculated particles. Because small particles have a large surface area, the pollutant load attached to small particles tends to be relatively greater than that attached to larger particles. The ability of runoff to transport suspended materials is highly dependent on the particle size (Mudgway *et al*., 1997). However the particle size distribution of the source material and transported sediment is important in determining the potential impacts on the receiving body.

2.4. IMPACTS ON RECEIVING WATER

The impact of poor stormwater quality is becoming an increasing issue of concern amongst catchment managers. The impacts can include increased turbidity and suspended solid concentrations, deposition of suspended materials, increased numbers of micro-organisms, changes in water temperature and pH, and decreased dissolved oxygen levels. In order to investigate the impact of the adverse quality stormwater on receiving waters, the receiving waters must have some characteristics of natural water systems. Mudgway et al. (1995) and CD&M (1993) have detailed the impacts of urban runoff pollution on receiving waters as follows:

- Eutrophication: overabundance of aquatic plants which reduces light infiltration into the water and when senescent, leads to oxygen depletion caused by excess nutrients (e.g. blue algae which can also be toxic)
- Oxygen depletion: caused by organic material degradation by micro-organisms and oxygen-demanding substances
- Disease: caused by pathogenic organisms which may be consumed in water or food provided from the contaminated water body
- Sedimentation: caused by particulate matter; sediment also affects photosynthetic and reparative process
- acidification: caused by atmospheric deposition
- Aesthetic decline: caused by floating litter and organic material, and the surface films of oil and grease
- Reduction in biotic diversity: mortality of organisms due to chronic or acute toxicity caused by pollutants such as heavy metals and agricultural chemicals

Common pollutants, sources and their impact found in urban stormwater runoff are classified by Peluso *et al*. (2002) in Table 2-1.

Table 2-1 Pollutants in Stormwater Runoff

Pollutant	Sources	Impact to Water Body
Sediments	Eroding rock, soil or organic material from building sites, streets and lawns	Clogged waterways, increased turbidity and reduction of bottom-living organisms
Nutrients	Nitrogen and phosphorous from landscape runoff, atmospheric deposition and faulty septic tanks	Unwanted growth of algae and undesirable aquatic weeds, scum and water discolouration
Heavy Metals	Lead, cadmium, chromium, copper, mercury and zinc from vehicles, highway, atmospheric deposition and industry	Disruption of fish reproduction, fish toxicity and potential for ground water contamination
Oxygen-demanding Substances	Decaying organic matter	Death of fish and aquatic life forms
Petroleum Hydrocarbons	Oil, grease and various hydrocarbons from roads, parking lots, leaking storage tanks and improper oil disposal	Toxicity to aquatic life and adverse impacts on benthic communities
Pathogens	Coliform bacteria and viruses from animal waste, septic systems, sewer cross-contaminations, boats and marinas	Contamination of swimming, fishing areas and drinking water
Toxics	Pesticides, solvents and chemicals from lawns, gardens, and commercial and household activities	Interference with respiration of fish and aquatic life forms
Others	Changes in the temperature or physical properties of water	Increased oxygen demand by fish and aquatic life forms and increased availability of toxic elements that harm organisms

Source: Pleuso et al., 2002

2.5. STORMWATER POLLUTANTS

2.5.1. GROSS POLLUTANTS

During storm events, large amounts of urban debris are flushed from the catchment into the stormwater drainage system. This debris is often referred to as gross pollutants and includes all forms of solids such as urban-derived litter, vegetation and coarse sediment. Gross pollution is generally the most noticeable indicator of water pollution to the community. Apart from the visual impact of gross pollutants, they can also contribute to a reduction in the drainage capacity of stormwater conveyance systems. When deposited into the receiving waters, they are a threat to the aquatic ecosystem through a combination of physical impacts on aquatic habitats and contamination of receiving water quality, owing to other pollutants such as oxygen-demanding material, hydrocarbons and metals associated with the gross pollutants.

There is no formal protocol for the monitoring of gross pollutants. A recent study by the Cooperative Research Centre for Catchment Hydrology (Allison *et al*., 1997) has found organic material (i.e. vegetation – particularly twigs, grass clippings and leaves) to constitute the largest proportion of gross pollutants carried by stormwater. This was found to be the case for all land use types. Human-derived litter makes up approximately 25–30% of the total gross pollutant load. Of the human-derived litter, paper was found to be the dominant pollutant type. A related study of litter on urban streets resulted in similar findings by the Moreland City Council and Merri Creek Management Committee (1997). Pollution of the environment from the export of litter and other urban-derived gross pollutants has intensified over the last 30 years due to the production of easily disposable, non-biodegradable packaging of household, commercial and industrial items. The sources of litter are varied, and include dropping of rubbish, overflows of rubbish containers and material blown away from tips and other rubbish sources.

For the purpose of this research, gross pollutants are defined as materials larger than five millimetres including litter, vegetation, sediments and floatable. These are transported by stormwater runoff into receiving waters (urban, creeks, rivers and estuaries) (Allison *et al*., 1997). Gross pollutants in stormwater runoff can also contain medical waste including needles that may be hazardous to human and other litter, including cigarette butts, plastics, paper, glass and Styrofoam which are offensive and unsightly (James, n.d.). "Significant amounts of gross pollutants are mobilized into stormwater systems during bursts of rain, wind or both" (Walker & Wong, 1999).

There have been many studies conducted to monitor and estimate gross pollutants in urban area stormwater runoff. Results from the Environment Australia (2002) study indicate that about three-quarters of gross pollutants are organic material, mainly leaves and twigs. Allison and Chiew (1995) found that natural material such as twigs and leaves in the Coburg area contributes at least two thirds of gross pollutant loads and commercial areas were found to have larger amounts of human-derived materials (paper and plastics) than other areas. Allison et al. (1997a) undertook an investigation into the types of gross pollutants derived from urban catchments. The study found typical urban gross pollutants transported by stormwater included litter (predominantly paper and plastics) and vegetation (leaves and twigs).

Australian field studies found significant loads of gross pollutants in stormwater drainage from urban areas that had been subject to a daily street sweeping regime. In Melbourne, Walker and Wong (1999) suggested that gross pollutant loads in stormwater draining urban areas depend more on the nature of rainfall (i.e. the available *energy* to mobilise and transport gross pollutants) than reductions to the load of gross pollutants on the street surface (i.e. through street sweeping). Approximately 35% of all recorded rainfall events in Melbourne are greater than 3.7 mm giving an average inter-event dry period of 178 hours (7.4 days) for gross pollutant transporting storm events.

The observed composition of the gross pollutant material collected by Nilson et al. (1997) was consistent with other studies conducted by Sartor and Boyd (1972), O'Brien (1994) and, Allison and Chiew (1995), where gross pollutant load measured in dry mass comprised approximately 70–90% organic matter, and 10–30% litter.

Nonetheless, vast quantities of gross pollutants reach Port Philip Bay. Allison (1997) determined that urban areas contribute approximately 30 kilograms per hectare per year of dry gross pollutants to stormwater systems. The average density of gross pollutants was found to be 260 kilograms per cubic metre. This figure was extracted for Melbourne to give a figure of approximately 230,000 cubic metres of gross pollutants and 1.8 million items of litter per year (Justin, 2002).

Estimates of the gross pollutant loads vary due to the different measures used in determining quantities. Nielson and Carleton (1998), for example, counted individual pieces while Webster and Sim (1992) used volume of contaminants. A third approach has been presented by Essery (1994) who used mass flux in determining loads. A typical annual gross pollutant load for an urban environment is quoted by Allison et al. (1998) as being 250 kg/ha. The quantity of gross pollutant is large, estimated to be between 8–15 cubic feet per acre per year. ASCG Incorporated (2005) has used an average generation of 10 cu.ft./acre/year for roadway runoff.

It is found that gross pollutant materials that have less than 1.0 specific gravity (S.G.) are particularly likely to be picked-up (Justin, 2003). Storm event monitoring showed that the highest concentrations of gross pollutants were during the early stages of runoff events (first flush). However, the largest quantities of material (loads) were being transported during times of high discharge (Allison *et al*, 1997, Environment Australia, 2002). Although gross pollutant loads and concentrations vary considerably during runoff events, the composition of the gross pollutants remains relatively consistent. (Environment Australia, 2002).

2.5.2. SEDIMENT/SUSPENDED SOLIDS

The importance of fluvial sediment to the quality of aquatic and riparian systems is well established. The U.S. Environmental Protection Agency (1998) identified sediment and suspended solids (SS) as the single most widespread cause of impairment of the nation's rivers and streams, lakes, reservoirs, ponds and estuaries. Reliable, quality-assured data on sedimentation and ancillary information are the underpinnings for the assessment and remediation of sediment-impaired waters.

2.5.3. LABORATORY AND METHODS

Two standard methods are widely cited in the United States for determining the total amount of suspended material in a water sample. These are:

Method D 3977-97, "Standard Test Method for Determining Sediment Concentration in Water Samples" of the American Society for Testing and Materials, 2000, and
Method 2540 D, "Total Suspended Solids Dried at 103^o- 105^oC" of the American Public Health Association, American Water Works Association and Water Pollution Control Federation, 1995.
The differences in these analytical methods, and some variations used to produce TSS (total suspended solids) data are described below.

2.5.3.1. Suspended-Sediment Concentration (SSC) Analytical Method

ASTM Standard Test Method D 3977-97 lists three methods that result in a determination of SSC values in water and wastewater samples:

1. ***Test Method A*** - Evaporation: The evaporation method may only be used on sediment that settles within the allotted storage time, which can range from a few days to several months. If the dissolved-solids concentration exceeds about 10 percent of the SSC value, an appropriate correction factor must be applied to the SSC value.

2. ***Test Method B*** - Filtration: The filtration method is used only on samples with concentrations of sand-size material (diameters greater than 0.062 mm) less than about 10,000 mg/l and concentrations of clay-size material of about 200 mg/l. No dissolved-solids correction is needed.
3. ***Test Method C*** - Wet-sieving filtration: The wet-sieve filtration method also yields a SSC value, but the method is not as direct as Methods A and B. Method C is used if the percentage of material larger than sand-size particles is desired. The method yields a concentration for the total sample, a concentration of the sand-size particles, and a concentration for the silt- and clay-size particles. A dissolved-solids correction may be needed, depending on the type of analysis done on the fine fraction of the samples and the dissolved-solids concentration of the sample.

These three methods are virtually the same as those used by USGS sediment laboratories and described by Guy (1969). Only the Whatman Grade 934AH, 24 mm diameter filter is used for purposes of standardisation. Each method includes retaining, drying at $103^{o}C \pm 2^{o}C$, and weighing all of the sediment in a known mass of a water-sediment mixture (U.S. Geological Survey, 1999a).

2.5.3.2. Total Suspended Solids Analytical Method

According to the American Public Health Association, the American Water Works Association and the Water Pollution Control Federation in 1995, the TSS analytical method uses a predetermined volume from the original water sample obtained while the sample is being mixed with a magnetic stirrer. An aliquot of the sample—usually 0.1 L, but a smaller volume if more than 200 mg of residue may collect on the filter is withdrawn by pipette. The aliquot is passed through a filter, the diameter of which usually ranges from 22 to 125 mm. The filter may be a Whatman Grade 934AI-L Gelman Type A/E, Millipore Type AP40, E-D Scientific Specialties Grade 16 1, or another product that gives demonstrably equivalent results. After filtering, the filter and contents are removed and dried at $103–105^{O}C$, and weighed. No dissolved-solids correction is required. The percentages of sand-size and finer material cannot be determined using the TSS method.

Various studies and experiments overseas shows that street surface particle matter has been described as having particle sizes ranging from about 3000 to 74 μm and less (Sarto and Gaboury, 1984). A collection of reported particle size distribution curves for solids found on street surfaces and in street surface and highway runoff is shown in Figure 2.1.

The collection of 20 particle size distribution curves presented in Figure 2.1 are derived from sampling solids from a number of overseas and Australian catchments. Despite the overseas data being collected from a variety of sources, locations and by various methods, they show a consistent distribution ranging from approximately 10 μm to approximately 10,000 μm. The particle size distributions derived from sampled road runoff from two Australian sites, one as part of an ongoing CRC project and the other by Ball and Abustan (1995), are also presented and appear to fall outside the range of the particle size distribution curves of the overseas catchments. The Australian data (ranging from 2 μm to approximately 500 μm) displays a significantly finer particle size distribution*, with a greater percentage of particles less than 125 μm (up to 70%). Although only based on sampling at two sites, the inefficiencies of street sweeping in removing particles less than 125 μm would result in little removal of up to 70% of the particles found in runoff in these Australian catchments. Therefore, the difficulty for Australian street sweeping, is the fine nature of the sediment found on roads. [*Up to 70% of particles found on street surfaces are less than 125 μm compared to 20% for overseas road runoff data.]

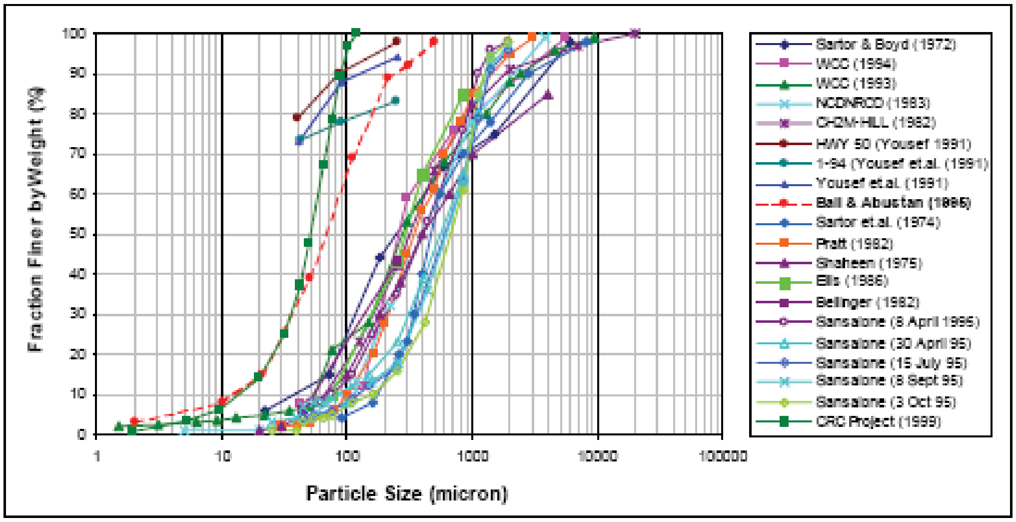


Figure 2.1 Litters and Debris in street Sweeping

The effect of coarse sediments transported from urban areas has physical impacts on receiving aquatic environments by choking marine habitats and clogging-up waterways, causing a reduction in waterway discharge capacity. The Centre for Streamside Studies (1991) reported that total suspended sediment at concentrations of 300–400 mg/l may reduce the visibility of fish and impair their search for food and sustained high concentrations of suspended solids could reduce primary production (if other factors are not limiting).

2.5.4. LITTER

In years to come, archaeologists sifting through the remains of late 20th Century civilisation might well come to identify this period of history as one of waste – "the throw-away society". In South Africa this is most clearly demonstrated by the large quantities of urban litter (alternatively called trash, debris, flotsam, jetsam, rubbish or solid waste) that is so often to be seen strewn about in public places. The litter, consisting mainly of manufactured materials such as bottles, cans, plastic and paper wrappings, newspapers, shopping bags and cigarette packets—but also including items such as used car parts, rubble from construction sites, and old mattresses—accumulates in the vicinity of shopping centres, car parks, fast food outlets, railway and bus stations, roads, schools, public parks and gardens, garbage bins, landfill sites and recycling depots. There it remains until it is either removed by the local authority, or it is transported by the wind and/or stormwater runoff into the drainage system (Armitage & Rooseboom, 2000).

Urban litter, defined as visible solid waste emanating from the urban environment (Armitage *et al.,* 1998) and henceforth called simply ‘litter’, is extremely difficult to trap and remove once it has entered the drainage system. Although much effort has been expended on the development of trapping devices, most of the traps currently installed are extremely ineffective at trapping and storing urban litter.

Litter has been reported in the literature using a wide range of sizes as the lower limit (5–10 mm). These have usually been selected to match the size of the mesh in the type of device used to collect the litter. In this study, the boundary of 4.75 mm (close to 5 mm) was selected as the lower limit for litter and organic debris since it would be impossible to separate smaller fragmented particles from the coarse sediment size fraction.

In addition, this size can be conveniently separated in the laboratory using a #4 U.S. sieve size and includes the 5–10 mm size reported by other studies (Caltran, 2000; Allison *et al*., 1996; Allison *et al*., 1998; Hydroqual, 1995; Armitage & Rooseboom, 2000; Lloyd et al., 2001; Butler et al., 2002). In addition, the #4 sieve corresponds to the separation between coarse sand and gravel (ASTM standard D 2487-92).

The study of ASCE Guideline for Monitoring Stormwater Gross Solids (2005) indicates that the volume of litter removed ranged from 28-1,500 cubic feet per square mile of upstream drainage area. It also shows that the average gross pollutant removed from all facilities is 64 cubic feet per square mile (0.1 cu.ft./acre). This is very lower than the typical range quoted from other sources in the range of 5–15 cu.ft./acre/year. The research of Nielsen and Carleton, 1998 and Sim and Webster, 1992 reported that litter is the second largest gross pollutant component with approximately 25% of total volume within Australia. Most of the litter analysed—by mass and frequency—comprised paper and plastics. These enter the drainage network as street litter from mainly commercial areas. Large quantities of food, drink and cigarette refuse were also found during the monitoring. These findings suggest that fast food consumers and smokers are a significant source of litter in urban streams. Laboratory testing of gross pollutants showed that typically, only 20 percent of litter and less than 10 percent of vegetation usually floats. This has implications for traps designed to catch only floating material (Allison R. *et al*, 1997).

2.5.5. DEBRIS

Litter and debris in urban waterways are unattractive, disturb the physical habitat, degrade the water, attract pests and vermin, can cause marine animal deaths, can further promote littering and reduce amenity values (R.A. Allison *et al*., 1998). Debris is defined as any organic material transported by stormwater (such as leaves, twigs and grass clippings) as defined by DLWC (1996). Debris comes from both natural and anthropogenic sources with the distinction between the two sources being indistinct (ASCG, 2005). Vegetation however, is not a major source of nutrients compared to other sources. The CRC monitoring study indicated that the potential total phosphorus and total nitrogen loads from vegetation. In stormwater are about two orders of magnitude lower than the loads measured in stormwater samples. However, because of its large volume, plant matter should be taken into account in the design of gross pollutant traps, particularly where they could cause pipe blockages or habitat destruction (R.A. Allison *et al*., 1998).

Large stormwater flows invariably cause extensive pollution with high organic and sediments loads, sudden discharges from flooded sewers and growing piles of litter and rubbish being carried in drainage channels.

Figure 2.2 Litters and Debris in River (Allison *et al*., 1998)

The most obvious aspect of a pollution problem is deteriorating visual water quality. Outbreaks of blue-green algae, piles of foam, significant fish kills, cloudy and highly coloured water and oil slicks are examples of visual problems. Floating inorganic debris and litter, such as steel drums, car tyres, bottles, aluminium cans and foam boxes, raise community concerns. They can harm wildlife and damage their natural habitats as well as threatening public safety. Organic debris, such as leaves, timber, paper, cardboard and food will in the short term cause visual pollution. When this material decays, it releases nutrients. This may form rich organic sediment that can cause algal blooms.

Figure 2.3 Algal Blooms in a Nutrient-enriched Waterway Discharging into Adelaide's Gulf of St Vincent, South Australia (Department of Environmental Heritage 2002)

Nielson and Carleton (1998) and Sim and Webster (1992) have reported that the largest portion of the total gross pollutant is debris (comprising approximately 70%) in Australia.

A large percentage of gross pollutants are submerged or semi-submerged and do not float on the surface. Under some conditions, it has been reported that up to 80% of litter and 90% of the vegetation debris does not float on the surface (ASCG, 2005). A typical pollutant density (wet) of 15.5 lb/ft^3 and a wet-to-dry mass ratio of 3.3 to 1 were also found. It is reported that wet 'as collected' densities has a range of 8–32 lb/ft3 and approximately 10 lb/ft3 was measured for local debris (OCSP, 2003).

2.5.6. TOXIC ORGANICS, OIL and SURFACTANTS

The main sources of toxic organics, oils and surfactants are transport-related in terms of leaks from vehicle, car washing and poor practices in vehicle maintenance. Oils and surfactants deposited on road surfaces are washed off and go to receiving waters. Poor industrial practices in the handling and disposal of oils and surfactants are also a dominant mechanism by which these substances are discharged into receiving waters. Oil, grease and other surfactants are unsightly and add to the chemical oxygen demand on the water body. Colwill *et al*. (1984) found over 70% of oil and Polycyclic Aromatic Hydrocarbons (PAHs) to be associated with organic solids in the stormwater.

2.5.7. HEAVY METALS

Heavy metals are defined as substances that are usually single organic matter which are extracted from mine sites and purified in laboratory process. The characteristics of these elements are their high specific gravity and atomic weight. That is the reason they are called heavy metals. Urban stormwater runoff may contain abundant heavy metals such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn). These may come from a variety of sources including building materials (e.g. roofing, flashings and walls) and traffic-related sources (e.g. brake linings, tyre wear, and auto catalysts), (Peng Wu & Yu-shan Zhou, 2009). Except copper and cadmium, the majority of metals are presented in particulate form.

Dry atmospheric deposition near urban centres, especially in arid or semi-arid regions such as Australian environments, represents a potentially important non-point source of particle-associated metals to water bodies. Atmospheric particulate matter may be directly deposited onto the surface of a water body or may reach the water body indirectly through deposition onto the land surface during dry periods, followed by subsequent wash-off during storm events.

The combination of high vehicle movement in industrial areas and service stations produces elevated levels of heavy metals through normal vehicle wear and repair work. Lead that is primarily generated from emission of vehicles is usually associated with finer particulates (Christensen & Guinn, 1997). Metals such as iron, barium and caesium derive from brake lining (Hopke *et al*., 1998). Lead, zinc and copper found in stormwater, are washed into the drainage system after rain and may concentrate in sediment and bioaccumulation in living organisms. Atmospheric discharges from industry and vehicle emission (partially lead petrol emissions) are major sources of this type of run-off contamination (McKeown, 1999).

Most of the heavy metals in urban stormwater runoff are attached to suspended solids (Bodo, 1989; Dong et al., 1984). Furthermore, metal concentrations generally increase with decreasing particle size (Liebens, 2001; Ujevic *et al*., 2000). This is due to the relatively large surface area of fine sediments and their higher Cation Exchange Capacity (Dong *et al*., 1984). Since most metals have a greater affinity for smaller particle sizes, conventional pollutant abatement programmes such as street sweeping (which only picks up large particles) have little effect in reducing toxic runoff levels, as fine suspended solids are readily transported in stormwater. In addition to the relationship between suspended solids and metals, parameters such as rainfall intensity and rainfall volume have been noted as important factors in influencing the export of heavy metals from an urban area (Sonzogni *et al*., 1980). Despite the strong affinity between heavy metals and suspended solids, the evaluation of the dissolved fraction of the heavy metal load is important as an indicator of bioavailability.

A relevant research project was conducted by Queensland University of Technology at three sites (residential, commercial and industrial) which were located in the Gold Coast region just south of the Queensland state capital, Brisbane, Australia. The Gold Coast region is a popular holiday destination and has one of the highest population growth rates in the country. It has a subtropical climate with wet summers and dry winters. The samples from the different sites were initially evaluated individually and were later compared to identify similar pollutant behaviour between the sites. In order to assess relationships between heavy metals and physio-chemical parameters, Principal Component Analysis (PCA) was used. GAIA was used as a visualisation tool for correlations between physio-chemical parameters and heavy metals. GAIA also revealed correlations between the heavy metals themselves and in which particle size and site they dominated. In the PCA analysis, all the parameters were given the same weighting and preference functions. The preference function was set to V-shape, which meant that a preference threshold P, representing the smallest deviation considered decisive was used in processing the data. P was set to the maximum concentration of each variable. Concentrations below the detection limit were set to half the detection limit value of the specific parameter (Guo *et al*., 2004). The concentration range of each parameter at the sites is shown in Table 2-2.

Table 2-2 Concentration Range and Deviation from Mean (Guo *et al*., 2004)

Parameter	Range			Standard deviation		
	Res	Ind	Com	Res	Ind	Com
pH	6.7-7.3	6.5-6.8	6.6-7.7	0.2	0.1	0.3
EC [µS/cm]	102-130	287-665	27-57	10	135	9
TOC [ppm]	<0.001-4.0	<0.001-2.9	<0.001-3.9	1.0	0.6	0.8
IC [ppm]	<0.001-3.6	<0.001-1.8	<0.001-1.9	1.2	0.4	0.4
DOC [ppm]	<0.001-9.4	<0.001-9.1	<0.001-8.9	3.1	2.9	2.5
TSS [ppm]	0.5-76.3	2.1-86.0	10.3-49.5	14.8	16.7	9.2
TDS [ppm]	60.0-95.0	60.0-250.0	10.0-40.0	32.0	77.4	10.0
Zn [ppm]	<0.001-3.6	<0.001-0.5	<0.001-0.7	0.7	0.1	0.2
Cu [ppm]	<0.001-0.4	<0.001-0.04	<0.001-0.1	0.08	0.007	0.03
Pb [ppm]	<0.001-0.02	<0.001-0.03	<0.001-0.01	0.002	0.005	0.002
Al [ppm]	<0.001-0.6	<0.001-0.4	<0.001-0.3	0.2	0.09	0.05
Fe [ppm]	<0.001-0.7	<0.001-0.9	<0.001-0.7	0.2	0.2	0.1
Cd [ppm]	< 0.001-0.3	<0.001-0.001	<0.001	0.05	0.0002	<0.001
Cr [ppm]	<0.001-0.007	<0.001-0.02	<0.001-0.003	0.002	0.003	0.001
Mn [ppm]	<0.001-0.01	<0.001-0.02	<0.001-0.01	0.003	0.004	0.003

Res = Residential; Ind = Industrial; Com = Commercial

As it can be seen in above Table, correlations occur between Total Dissolved Solids (TDS), Zn, Cu and Dissolved Organic Carbon (DOC) since variables in general agreement are oriented in the same direction as the GAIA plane. It also reveals a relationship between Total Suspended Solids (TSS) and the metals Pb, Fe, Al and Mn. EC and pH has a negligible effect on the heavy metal concentration, whilst Cr is slightly correlated with the Total Organic Carbon (TOC). It can now be noticed that three major particle size clusters occur with particles larger than 300µm, particles smaller than 0.45µm and particles between 0.45–150µm. Al, Fe, Pb and Mn are correlated with particles between 0.45–150µm. This is of serious concern since the particle size distribution analysis showed that the majority of particles in urban stormwater are between 0.45–150µm. Since most of the metals are correlated with smaller particle sizes, conventional cleaning programmes would have little or no effect in reducing toxic runoff levels and fine suspended solids are readily transported in urban stormwater. At all three sites (residential, industrial, commercial), Zn was correlated with DOC. Cu and DOC were correlated at the residential and commercial sites. However, Cu was correlated with TSS at the industrial site. Pb, Fe and Al were correlated with TSS at all three sites and the majority of these metals were found in the size range 0.45–75µm. It is postulated that DOC and TSS could serve as indicators of the distribution of these metals in urban stormwater. Consequently, parameters such as DOC and TSS, which are relatively easy to monitor, could be used as indicators of the distribution of metals such as Zn and Pb. Furthermore, DOC and TSS measurements could help determine the characteristics of urban stormwater quality management practises such as street sweeping and retention/detention ponds.

2.5.8. NITROGEN AND PHOSPHOROUS

As organic waste breaks down in a waterway a number of natural compounds such as nitrogen and phosphorus, which are essential to plant and animal life, are released. In their natural state, Australian soils and waterways are generally low in nutrient content, and consequently, the organisms living in Australian waterways have adapted to low nutrient conditions. Australian stream biota is therefore especially susceptible to excess nutrients in waterways. An excess of nitrogen (in marine systems) or phosphorus (in freshwater systems) can stimulate aquatic life to the extent that plant growth becomes a major problem for a water body. Excessive plant growth can choke waterways and lead to large fluctuations in dissolved oxygen levels, which threaten fish and other animals in the water body. During the day, the production of oxygen more than compensates for the oxygen consumed by organisms, including useful bacteria. However, during the night, the oxygen consumed by aquatic plants and animals can deplete oxygen to a level which can be dangerous to fish and other organisms. Eventually, plants die off in massive quantities, resulting in a further drop in oxygen levels as the dead plants decompose. The sources of nutrients can be identified in humans and many organic and human-used materials and substances. Major sources of nutrients are:

- human or other animal wastes
- plant matter (cuttings, leaves, whole plants)
- organic wastes
- fertilisers
- detergents
- kitchen wastes
- nitrous oxides produced by car exhaust and lightning
- ash following forest fires
- landfill leachate

Fertilisers such as blood and bone, super phosphate, seaweed and animal manure are used widely on private gardens and on the many parks and golf courses that are close to waterways which drain to Port Phillip Bay and Western Port (Guo *et al*., 2004). . Stormwater runoff from these areas contributes phosphorus and nitrogen to our waterways. In the rural areas of catchments, commercial fertilisers (e.g. super phosphates) are applied widely to support intensive agriculture such as market gardens, feedlots, crops and orchards. Washing cars and boats on pavements and driveways with detergents containing phosphates also contributes to the amount of phosphorus entering our waterways. Eroding soil surfaces in both urban and rural areas are a further source of nutrients, particularly phosphorous.

2.6. TREATMENT METHODS

To protect receiving waters from stormwater pollution requires design and implementation of stormwater treatment strategies often involving a substantial investment in the construction of stormwater treatment measures. Several stormwater treatment measures are used to prevent pollutants entering waterways and measures include: ponds, wetlands, retention basins, detention basins and vegetated swales depending on the nature of the stormwater pollutants being targeted, and also on scale and available space (Tony *et al*., 2005). There are some other removal methods that have been implanted, such as wet wells and street sweeping. These methods may require either labour-intensive or maintenance-intensive methodology or both. The vortex separator method which uses vortex phenomena is an underground removal method. The vortex phenomena method is a new technique used in gross pollutant traps to remove pollutants up to the aperture of the stainless steel basket which is located in the centre of the storm pollutant trap (SPT). Whatever method is used, the first evaluation is based on the capabilities and limitations of the physio-chemical process of the environment. Then the applicability of the process to stormwater treatment is addressed. Improving the understanding of relationships between a catchments' land usage, the physical characteristics of the land and the characteristics of stormwater originated from that catchment, are major factors for designing stormwater treatment measures and understanding ecosystem responses (Fletcher, 2001). Some affecting factors of stormwater treatments are:

- Physio-chemical characteristics of contaminants (Ph, temperature, etc.)
- Type of contaminants
- Volume to be treated
- Concentration of contaminants
- Particle size distribution
- Flow rate
- Type of contaminants (in suspension, dissolved, attached to particles)

The different combinations of stormwater treatment considerations makes prefabricated treatment devices a challenging prospect and suggest that stormwater treatment devices will not be able to achieve the same removal effectiveness as conventional water and wastewater treatment plants (Engineering Fundamental Report, 2000).

2.6.1. DETENTION BASINS / RETENTION BASIN

Retention is defined as the process of preventing rainfall runoff from being discharged into receiving water bodies by holding it in a storage area. The water may then infiltrate into groundwater, evaporate or be removed by evapo-transpiration of vegetation.

Retention systems are designed to prevent off-site discharges of surface water runoff, up to the designed Average Recurrence Interval event (Stormwater Management Manual for Western Australia: Retrofitting, 2006).

Detention is defined as the process of reducing the rate of off-site stormwater discharge by temporarily holding rainfall runoff (up to the designed Average Recurrence Interval event) and then releasing it slowly, to reduce the impact on downstream water bodies and to attenuate urban runoff peaks for flood protection of downstream areas as shown in Figure 2.4 (Stormwater Management Manual for Western Australia: Retrofitting, 2006).

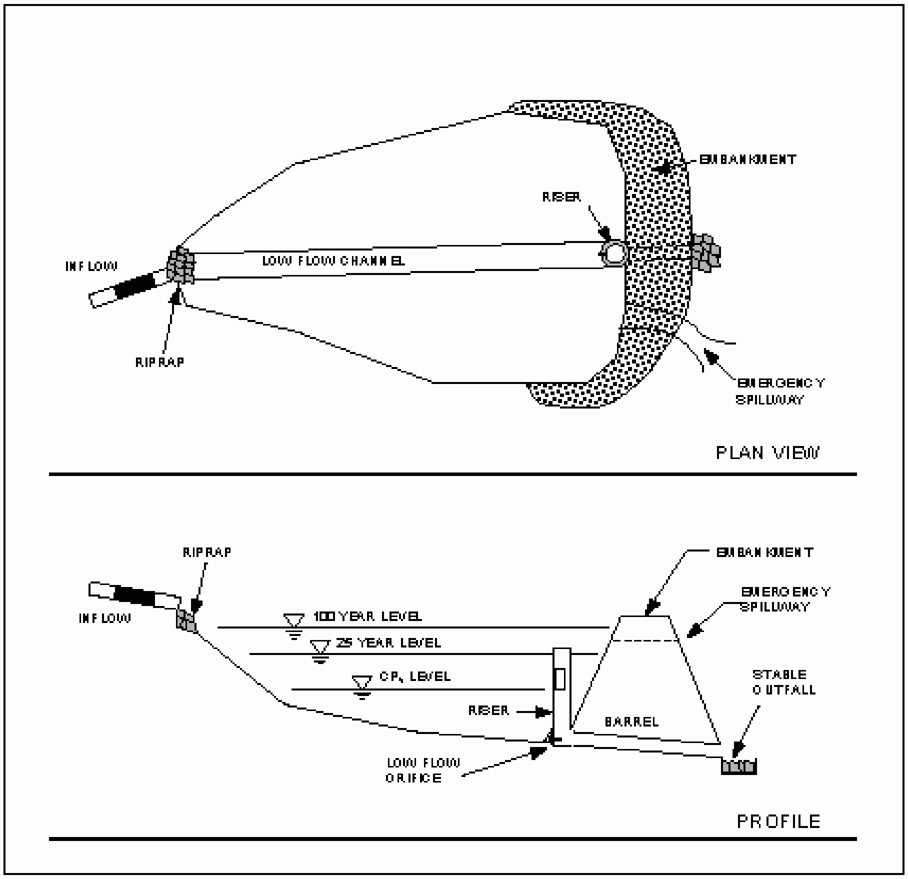


Figure 2.4 Plan and Profile View of Detention Basin (Stormwater Management Manual for Western Australia: Retrofitting, 2006)

Before urbanisation, most leaves, rotting vegetation, animal droppings, sticks, dust and sand stayed more or less where they fell. Now the ecology of many urban waterways is changed forever. Excessive amounts of organic material are washed from expanses of sealed surfaces, accumulate and then break down on the bottom of rivers and harbours. This process creates a stagnant environment, reducing the oxygen available for aquatic life. The increased stormwater flows from urbanisation can accelerate stream velocities and cause severe stream channel erosion. Sediment washed off construction sites and other unsealed surfaces is discharged into the same waterways, causing increased siltation and affecting the local currents required to sustain a healthy environment. This can impact on natural wetlands and the biodiversity of waterways. As well, litter pollution in the stormwater system increases risks to human health and can destroy food sources or the habitats of aquatic life (Witheridge & Grant, 1998).

Figure 2.5 Extended Detention Basin Full and Empty (www.dcr.virginia.gov/soil and water/documents/chapter-3-07.pdf)

Retention basins as shown at Figure 2.5 are widely regarded as artificial wetlands, and in new suburban developments in Western Australia and elsewhere in Australia, are now so common that they are virtually mandatory. Visually they have come to be part of the package to give an instant focus for public open space and are central to the process of planning and design of new suburban sites. Constructed basins in Western Australia usually deliberately and permanently expose and reveal groundwater lenses, more usually at the lower levels of the landscape, with the aim to provide the viewer a year-round view of a water body Figure 2.6. Once constructed, they can also be used as the receiving point for stormwater runoff. This can be in the form of direct discharge but some more recent developments incorporate retention systems to slow velocity, accommodate the settling of carried particles and provide for some degree of nutrient stripping through appropriate planting of wetland vegetation.

Figure 2.6 Retention Basins, SE Perth. Showing Necessary Water Fountain, which Signals Artificiality of Whole System to Viewer, and Retaining Walls with Mined Limestone (M. Grose & D. Hedgcock, WA)

Constructed wetlands aim to control systematically and optimise the ability of a wetland system to remove or transform stormwater pollutants and in many cases, to also create an aesthetic environment for the development of wildlife and social objectives (Wood, 1995). The detention of urban stormwater in constructed ponds and wetlands is a widely adopted strategy for improving stormwater quality. These detention systems are often utilised to serve multiple functions related to urban landscape design, and flora and fauna conservation (Somes *et al*., 2000).

Detention basins are basically categorised as two types – dry and wet basin. Dry detention basins are normally dry, they detain runoff during and after the storm events, but their ability to permanently remove pollutants is limited since deposited materials are not removed, which are often resuspended by the next storm event. Therefore dry detention basins are not recommended for water quality improvement practice. In addition they are prone to clogging and resuspending of previously settled solids and require a higher frequency of maintenance than wet pounds if used for untreated stormwater flows as shown in table 2.3 below, otherwise they often become larger garbage collectors (Medge, 2001).

Table 2-3 Typical Dry Basin Removal Efficiencies (Medge, 2001)

Pollutant	Total Phosphorus	Total Nitrogen	Total Suspended solids	Lead	Zinc	Oil and Grease	Bacteria	BOD
Estimated Removal Efficiency	Low	Low	High	Moderate to High	Moderate	Low	High	Moderate

Structural management practices can be used to achieve four broad resource protection goals. These include: Flood Control, Channel Protection, Groundwater Recharge and Pollutant Removal. Dry extended detention basins can provide flood control, channel protection and some pollutant removal.

- ***Flood Control***

  One objective of stormwater treatment practices can be to reduce the flood hazard associated with large storm events by reducing the peak flow associated with these storms. Dry extended detention basins can easily be designed for flood control, and this is actually the primary purpose of most extended detention ponds in the ground today.

- ***Channel Protection***

  One result of urbanisation is channel erosion caused by increased stormwater runoff. Traditionally, dry extended detention basins have been designed to provide control of the two-year storm (i.e. the storm that occurs, on average, once every two years). It appears that this storm design has not been effective in preventing channel erosion, and recent research suggests that control of a shorter storm period may be more appropriate (MacRae, 1996). Choosing a shorter design storm period (one-year) and providing a longer detention time (12–24 hours) is now thought to be the best method to reduce channel erosion.

- ***Pollutant Removal***

Dry extended detention basins provide moderate pollutant removal, provided that the design features described in the *Sitting and Design* section are incorporated. Whilst they can be effective at removing some pollutants through settling, they are less effective at removing soluble pollutants due to the absence of a permanent pool. A few studies are available on the effectiveness of dry extended detention ponds. Typical removal rates are shown in Table 2.4, as reported by Winer (2000).

Table 2-4 Typical Pollutant Removal Efficiency of Dry Extended Detention Ponds (Winer, 2000)

Pollutant	Removal Rate (%)
TSS	61±32[1]
TP	20±13
TN	31±16
NOx	-2±23
Metals	29-54
Bacteria	78[2]

[1]: ± values represent one standard deviation

[2]: Data based on less than five data points

There is considerable variability in the effectiveness of ponds, and it is believed that properly designing and maintaining ponds may help to improve their performance. The sitting and design criteria presented reflect the best current information and experience to improve the performance of wet ponds. A recent joint project between the American Society of Civil Engineers (ASCE) and the US EPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice (BMP) database is a compilation of stormwater practices which includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. For more information on this database, access the ASCE web page at http://www.asce.org.

2.6.2. VEGETATED SWALES

A vegetated swale is a broad, shallow channel with a dense stand of vegetation covering the side slopes and bottom. Swales can be natural or man-made and are designed to trap particulate pollutants (suspended solids and trace metals), promote infiltration and reduce the flow velocity of stormwater runoff. Vegetated swales can serve as part of a stormwater drainage system and can replace kerbs, gutters and storm sewer systems. Therefore, swales are best suited for residential, industrial and commercial areas with low flow and smaller populations (Schueler, 1987). Vegetated swales can be used wherever the local climate and soils permit the establishment and maintenance of a dense vegetative cover. The feasibility of installing a vegetated swale at a particular site depends on the area, slope and precipitousness of the contributing watershed, as well as the dimensions, slope and vegetative covering employed in the swale system. Vegetated swales are easy to design and can be incorporated into a site drainage plan. While swales are generally used as a stand-alone stormwater in this sheet best management practice (BMP), they are most effective when used in conjunction with other BMPs, such as wet ponds, infiltration strips, wetlands, etc. (Southeastern Wisconsin Regional Planning Commission, 1991). Whilst vegetated swales have been widely used as stormwater BMPs, there are also certain aspects of vegetated swales that have yet to be quantified. Some of the issues being investigated are whether their pollutant removal rates decline with age, what effect the slope has on the filtration capacity of vegetation, the benefits of check dams and the degree to which design factors can enhance the effectiveness of pollutant removal (U.S. EPA, 1991).

2.6.2.1. ADVANTAGES AND DISADVANTAGES OF SWALES

According to Storm Water Management for Industrial Activities, U.S. EPA, 1992, swales typically have several advantages over conventional stormwater management practice, such as storm sewer systems, including: the reduction of peak flows, the removal of pollutants, the promotion of runoff infiltration and lower capital costs. However, vegetated swales are typically ineffective in, and vulnerable to, large storms, because high-velocity flows can erode the vegetated cover. Limitations of vegetated swales include the following:

- They are impractical in areas with very flat grades, steep topography, or wet or poorly-drained soils
- They are not effective and may even erode when flow volumes and/or velocities are high
- They can become drowning hazards, mosquito breeding areas and may emit odours
- Land may not be available for them
- In some places, their use is restricted by law; many local municipalities prohibit vegetated swales if peak discharges exceed 140 litres per second (five cubic feet per second) or if flow velocities are greater than 1 metre per second (three feet per second)
- They are impractical in areas with erosive soils or where a dense vegetative cover is difficult to maintain

Negative environmental impacts of vegetated swales may include:

- Leaching from swale vegetation may increase the presence of trace metals and nutrients in the runoff
- Infiltration through the swale may carry pollutants into local groundwater

Standing water in vegetated swales can result in potential safety, odour and mosquito problems.

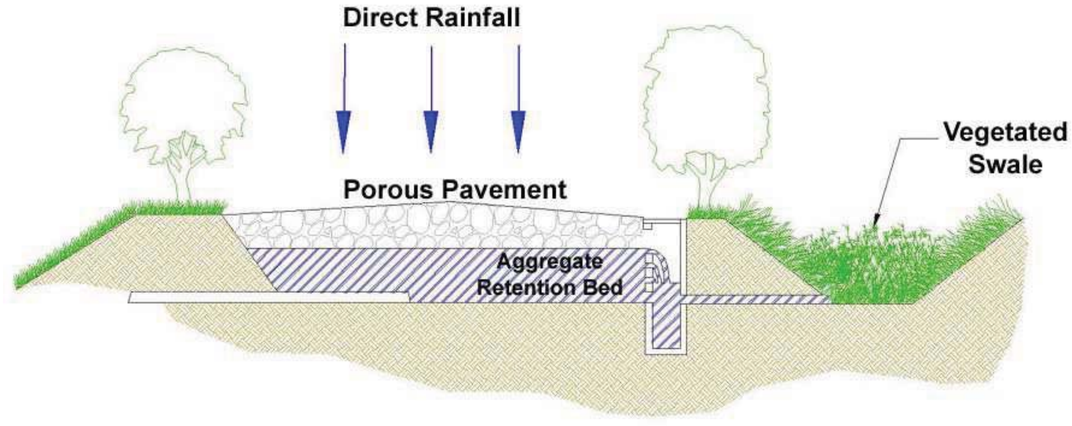


Figure 2.7 Schematic Showing Vegetated Swale Along Parking Area (Pennsylvania Stormwater Best Management Practices Manual, 2006)

Vegetated swales can serve as part of stormwater drainage systems and replace kerbs, gutters and storm sewer systems. Thus they are best-fitted for residential, industrial and commercial areas with low flow and smaller populations. The literature suggests that vegetated swales represent a practical and potentially effective technique for controlling and improving urban run-off quality (USEPA, 1999).

Conventional vegetated swales designs have achieved mixed results in removing particulate pollutants. Table 2-5 shows the result of such an experiment published by Engineers Australia, 2006.

Table 2-5 Typical Annual Pollutant Load Removal Efficiencies for Vegetated Swales

Pollutant	**Expected removal**	**Comments**
Litter	>90%	Should be 100%, provided there is adequate vegetation cover and flow velocities below 0.5 m/s
TSS	60 – 80%	Assumes low level of infiltration. Will vary with varying particle size distribution
Total Nitrogen	25 – 40%	Depends on specification and detention time
Total phosphorous	30 – 50%	Depends on specification and particle size distribution
Coarse sediment	>90%	Assumes re-suspension and scouring prevented by controlling inflow velocity<0.8 m/s and maintaining dense vegetation
Heavy metals	20 – 60%	Highly variable, depends on particle size distribution, ionic change, detention time, etc.

(Source: Engineers Australia, 2006)

2.6.3. WETLANDS

According to the NSW Department of Natural Resources, wetlands are land areas either temporarily or permanently covered by water and can be either natural or artificial with water that is still or flowing, fresh, brackish (slightly salty) or salty. This includes marine water which is no more than six metres deep at low tide. The classification of wetlands is an important first step in wetland management. Different wetland types respond differently to management tools, and wetlands need to be managed for a variety of reasons. Wetland classification can guide landholders and community groups with wetland management, and promote an awareness of wetland management issues (Green, 1997). The three types of wetlands are as follow:

Coastal Wetlands

- Mangrove and salt marsh swamps

- Estuarine lakes and lagoons
- Dune swamps and lagoons
- Coastal floodplain swamps and lagoons
- Coastal floodplain forest

Tableland Wetlands

- Upland lakes and lagoons
- Upland swamps

Inland Wetlands

- Permanent inland wetlands
- Inland floodplain lakes and lagoons
- Inland floodplain meadows
- Reed swamps
- Lignum swamps
- Inland floodplain forests and woodlands
- Arid wetlands

A key for identifying the wetland types appears below. The key begins with the broad geographic location. The wetland types are generally unique to each geographic region, with the exception of upland lakes and lagoons, and upland swamps. These two wetland types may occur in any of the three geographic regions, although are most common on the tablelands. This is reflected in the key, with these wetland types being included in all of the geographical regions. The wetland types are further described in the following pages. Each description consists of a simple definition of the wetland type followed by basic information on location (within the landscape and within the state, hydrology, vegetation, significance and management issues.

Presence of contamination might seriously limit the available options in wetland management. For example, wetlands may be created to provide flooding control. In highly-developed areas, surfaces are made impervious, wetlands are drained and rivers are canalised. This reduces the capacity of the aquatic system to store water during high discharge events. As a consequence, flooding frequencies and associated damage are increasing. Technological remedies such as the construction of dykes and flood barriers are limited, not in the least because of the excessive costs involved. Giving space back to the river by restoring wetland areas constitutes an affordable and sustainable flooding control (Tack *et al*., 2007). Wetlands are however, not solely a target of contamination. Interest in the engineered use of wetlands as a low cost and sustainable option for water treatment has significantly increased over the last decades. Because of technological requirements, and high investment and operation costs of conventional wastewater treatment solutions, it has been proven difficult to meet all demands for adequate waste water purification. Constructed wetlands are being considered as a sustainable, low-investment and low maintenance cost technology that can complement or replace conventional water treatment.

Using wetlands both natural and man-made—for capturing stormwater runoff and pollutants, has emerged from an understanding of the role wetlands naturally play in landscapes (Ewel & Odum, 1986; Mitsch & Gosselink, 1993; and Leibowitz *et al*., 2000). Specifically, wetland stormwater treatment areas (WSTAs) can provide the services of water storage and peak-flow attenuation (Ogawa & Male, 1986; DeLaney, 1995), nutrient cycling and burial (Richardson, 1985; Reddy *et al*., 1993), metal sequestration (Thurston, 1999; Odum *et al.*, 2000), sediment settling (Kadlec & Knight, 1996) and breakdown of organic compounds (Nix *et al.*, 1994; Knight *et al*., 1999). Numerous authors have highlighted constraints, benefits and design considerations for using wetlands to treat stormwater (Loucks, 1990; Stockdale, 1991; Rushton *et al*., 1997); and enhanced stormwater treatment basins exist where ecological and treatment objectives are simultaneously met (Knight, 1996; Otto *et al*., 2000). The use of constructed wetlands for the treatment of highway runoff, although well-established in the United States (Kadlec & Knight, 1997), is a relatively new technology in the U.K. (Shutes *et al.*, 2001). More extensive data sets have been reported for urban stormwater treatment with removal efficiency ranges for subsurface flow systems of 67–97% for TSS, 25–98% for N_{tot}, 5–94% for Pb_{tot} and 10–82% for Zn_{tot} (Strecker *et al*., 1992). The variability in performance was attributed to a number of factors including short-circuiting, short detention and contact times, pollutant remobilisation and seasonal vegetation effects. There is a need to design constructed wetlands for the treatment of highway runoff to address these and other factors, and Shutes *et al*. (1999) have commenced this process.

Schueler *et al*. (1997) summarised 123 research studies on the performance of ponds, wetlands, open channel systems, and filtering systems and devices. The report indicates most ponds and wetland design approached, but did not surpass, the 80% TSS removal threshold specified in CZARA 6271 guidance. Sheuler (1992) reported that the basis for the 80% standard is the removal efficiencies for control practices such as constructed wetlands, wet ponds and infiltration basins and used data.

The pollutant removal efficiencies of detention basins have been shown to be dependent on residence time with suspended solids removal decreasing from a maximum of 70% to 20% as containment time reduces from 48 to 2 hours (Stahre & Urbonas, 1990). The removal efficiencies of hydrocarbons, BOD and metals (Zn and Pb) were reduced by similar factors. Hares and Ward (1999) have indicated removal efficiencies in excess of 84% for a range of 11 metals in a 500 m^2 detention pond receiving runoff from a major motorway. For stormwater passing through a wet detention pond, Farm (2002) has reported average reduction rates of 26–84% for total metal content, 67% for N_{tot}, 78% for P_{tot} and 92% for COD. In an extensive study of retention ponds in the Florida area, Yousef et al. (1996) have reported average sedimentary accumulation rates of 1.3, 13.8 and 6.9 kg/ha year for Cu, Pb and Zn, respectively. Similar metal accumulation rates have been observed in French studies of retention basins (Lee *et al*., 1997) highlighting the need for regular inspection and maintenance of these systems. Pontier *et al*. (2001) have tracked the changes in Zn, Fe and Cu sediment concentrations across a vegetated balancing pond and shown an increase between inlet and outlet with the metals being predominantly associated with size fraction below 63 μm.

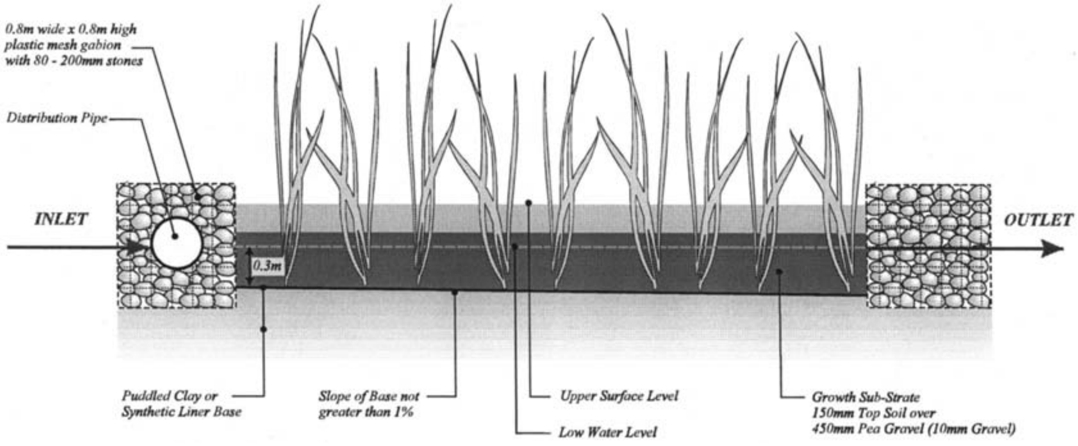


Figure 2.8 Section through Sub-surface Constructed Wetland

The use of constructed wetlands for the treatment of highway runoff, although well established in the United States (Kadlec & Knight, 1997), is a relatively new technology in the U.K. (Shutes *et al*., 2001). More extensive data sets have been reported for urban stormwater treatment with removal efficiency ranges for subsurface flow systems of 67–97% for TSS, 25–98% for N_{tot}, 5–94% for Pb_{tot} and 10–82% for Zn_{tot} (Strecker *et al*., 1992). The variability in performance was attributed to a number of factors including short-circuiting, short detention and contact times, pollutant remobilisation and seasonal vegetation effects. There is a need to design constructed wetlands for the treatment of highway runoff to address these and other factors (Shutes *et al*., 1999 has commenced this process. This paper contributes further to this approach and therefore also addresses the requirements of the Environment Agency for England and Wales, which include assessing methods for improving surface water management with an emphasis on sustainable drainage systems. Pollutant removal efficiencies reported by Strassler et al., 1999 and Winer, 2000 show that wetlands are one of the most effective methods of removing stormwater pollutants, particularly nitrate and bacteria. The variation observed in wetlands performance can be explained in part by relationship between key factors such as loading and input concentration which vary greatly in high dynamic processes influencing the stormwater flow and quality. Table 2-6 provides a summary of typical range of performance for stormwater wetlands with comments. The range represents an approximate standard deviation of the studied reviewed, at the same time the centre of the range can be used as an approximate estimate of typical performance (Fletcher, 2004).

Table 2-6 Summary of Typical Range of Performance for Stormwater Wetlands (Fletcher, 2004)

Pollutant	**Expected Removal (Mean annual load, %)**	**Comments**
Litter and organic matter	Very high (>95%) (s,p,w)	Subject to appropriate hydrologic control litter and coarse organic matter should ideally be removed in an aerobic environment PRIOR to a pond or wetland, to reduce potential impacts on BOD
TSS	60-85 (p) 65-95 (w) 50-80 (s)	Depends on particle size distribution
TN	30-70 (p) 40-80 (w) 20-60 (s)	Depends on specification and detention time
TP	50-80 (p) 60-85 (w) 50-75 (s)	Depends on specification and particle size distribution. Will be greater where a high proportion of P is particulate
Coarse sediment	Very high (>95%)	Subject to appropriate hydrologic control
Oil and grease	N/A	Inadequate data to provide reliable estimate, but expected to be >75%
Faecal Coliforms	N/A	Inconsistent data
Heavy metals	50-85 (p) 55-95 (w) 40-70 (s)	Quite variable: depends on particle size distribution, ionic charge, attachment to sediment (Vs. % soluble), detention time, etc.

(p) ponds, (w) wetlands, (s) sediment basin

2.6.4. STREET SWEEPING

The role and usefulness of street sweepers to control street surface pollutants was first investigated in the late 1950s and early 1960s by the United States Environmental Protection Agency (USEPA) and its associated researchers. Many of the USEPA's National Urban Runoff Program (NURP) studies measured the efficiency of street sweeping as a stormwater pollution control method with particular emphasis placed on sediment and sediment-bound contaminants. Since the late 70's, studies have measured street sweeping effectiveness in terms of the reduction in end-of-pipe runoff pollution concentrations and loads rather than assessing the effectiveness of specific equipment. Sartor and Boyd (1972) found sweeping schedules based on a seven-day cycle to be almost totally ineffective while daily sweeping was shown to potentially have a high level of pollutant removal for larger-sized pollutants typical of street surface material (Sartor & Gaboury, 1984).

Street cleansing is a common (and expensive) practice undertaken by most urban municipalities with annual expenditure by a municipality often exceeding one million dollars. Street sweeping, essentially the operation of large trucks for cleaning street surfaces is primarily performed for aesthetic purposes. Subsequent investigations into the effectiveness of street sweeper mechanisms for water quality improvement, report findings that vary to those presented in the conclusions of the earlier NURP studies. Alter (1995) and Sutherland and Jelen (1996b) assert that the NURP studies concluded that street sweeping is largely ineffective, because the sweepers used at the time of these studies were not able to effectively remove very fine accumulated sediments which are often highly contaminated. Sutherland and Jelen (1996a) suggest that street sweeping can significantly reduce pollutant wash off from urban streets due to the improved efficiencies of newer technologies now employed to conduct street sweeping in some American states. Their investigations showed that when street sweeping mechanisms and programmes are designed to remove finer particles (i.e. small-micron surface cleaners or tandem sweeping) it can benefit stormwater runoff quality.

The pollutant reduction effectiveness of any street sweeping operation is dependent on the equipment used and the environmental and geographic conditions (e.g. wind and presence of parked vehicles). Unless other influential factors (such as street parking) are addressed, the efficiency of individual sweeping mechanisms can be a relatively insignificant factor in the overall effectiveness of street sweeping operations.

According to Walker and Wong in (Technical Report 99/8, 1999), types of street sweeping mechanisms commonly utilised in Australian practice include:

- Mechanical broom sweepers involving a number of rotating brushes sweeping litter into a collection chamber

- Mechanical broom and vacuum systems involving the combination of rotating brushes and a vacuum to remove street litter
- Regenerative air sweepers which are like mechanical vacuum sweepers but use recirculated air to blast the pavement, dislodging litter before it is swept by rotating brushes towards a vacuum for pick-up. This sweeper also uses water sprays for dust suppression
- Small-micron surface sweepers which combine rotating brooms enclosed in a powerful vacuum head in a single unit, performing a dry sweeping/vacuuming operation. A powerful fan pulls debris and air into a containment chamber before the air is finally passed through a series of filters to capture small micron material

The most recent technology to be employed for street sweeping is a highly effective, vacuum-assisted dry sweeper (the small-micron surface sweeper) originally developed and manufactured by Enviro Whirl Technologies Inc. in the United States of America. The sweeper was originally developed for the containment of spilled coal dust along railway tracks. This system is reported to be extremely effective in removing fine street surface sediments and preventing their escape into the air by filtering air emissions down to sizes as small as 4 μm. Sutherland and Jelen (1997) described this system as having an advanced ability, when compared to other sweeping mechanisms, to remove a broad range of particles from road surfaces down to sub-micron particulates. The small-micron surface cleaning technology has been shown by Sutherland and Jelen (1997) to have total removal efficiencies ranging from 70% for particles less than 63 μm up to 96% for street surface pollutants larger than 6370 μm. Despite there being new street sweeping technologies reported to be more efficient, most municipalities and private street sweeping companies in Australia continue to use the mechanical broom and regenerative air vacuum street sweepers. This is because of the high capital costs of newer technologies and their limited availability on the Australian market.

Street sweeping performance for smaller street surface particles depends considerably on the type of street sweeper used and also conditions such as the character of the street surface (texture, condition and type), street dirt characteristics (loadings and particle sizes) and other environmental factors (Pitt & Bissonnette, 1984). Sartor and Boyd

(1972) found the removal efficiencies of sediment by conventional street sweepers to be dependent upon the particle size range of the street surface loads as shown in Figure 2.1

Mechanical sweeper efficiency was found to be generally low for fine material. This finding was supported by two further studies conducted by Bender and Terstriep (1984) and Pitt and Bissonnette (1984), who reported that the proportion of the total street load smaller than 300 µm was less affected by street sweeping. Pitt and Bissonnette (1984) also demonstrated that no effective removal was evident for street dirt particles smaller than about 125 µm for the regenerative air sweeper.

Figure 2.9 Street Sweeper Truck (Walker and Wong Technical Report 99/8, 1999)

Vacuum-assisted and regenerative air sweepers are generally more efficient than mechanical sweepers at removing finer sediments, which often bind a higher proportion of heavy metals (Table 2-7). The performance of sweepers can be enhanced by operating them at optimal speeds (11–15 km/h). Tests conducted on the newer vacuum-assisted dry sweepers have shown they have significantly enhanced capabilities to remove sediment compared to conventional sweepers, with projected reductions of up to 79 per cent in total suspended solids loadings from urban streets. In addition, these sweepers are extremely effective at removing respirable (PM-10) particulate matter (particles with an aerodynamic diameter less than or equal to 10 microns) compared to conventional sweepers (Table 2-8) and are designed to help meet National Ambient Air Quality standards.

Table 2-7 Efficiencies of Mechanical (Broom) and Vacuum-Assisted Sweepers

Constituent	Mechanical sweeper efficiency (%)	Vacuum-assisted sweeper efficiency (%)
Total Solids	55	93
Total Phosphorus	40	74
Total Nitrogen	42	77
COD	31	63
BOD	43	77
Lead	35	76
Zinc	47	85
Source: NVPDC (1992), as cited in Young *et al*. (1996)		

Table 2-8 PM-10 Particulate Removal Efficiencies for Various Sweepers

Sweeper Type	Removal Efficiency (%)
Mechanical - Model 1	6.7
Mechanical - Model 2	8.6
Regenerative Air	31.4
Vacuum-assisted wet - Model 1	40.0
Vacuum-assisted wet - Model 2	82.0
Vacuum-assisted dry	99.6
Source: U.S. Department of Transportation. Federal Highway Adminstration	

A collation of reported particle size distribution curves for solids found on street surfaces and in street surface and highway runoff is shown in Figure 6.3. The collection of 20 particle size distribution curves presented in Figure 6.3 are derived from sampling solids from street surfaces and suspended sediment collected in road runoff from a number of overseas and Australian catchments. The Australian sampled road runoff data displays a significantly finer particle size distribution, with a greater percentage of particles less than 125 μm (up to 70%). Although only based on sampling at two sites, the inefficiencies of street sweeping in removing particles less than 125 μm would result in little reduction of up to the 70% of the particles found in runoff in these Australian catchments. The difficulty for Australian street sweeping is the fine nature of the sediment found on roads. Up to 70% of particles found on street surfaces are less than 125 μm compared to 20% for overseas road runoff data. The inefficiencies of street sweeping in the reduction of sediment-bound pollutants entering the stormwater system is therefore expected to have more severe implications under typical Australian conditions. The study by Hall and Phillips (1997) also involved comparing accumulated litter items from street surfaces and side entry pit traps (SEPTs) in drains following rainfall events. The Carnegie urban catchment was monitored over a seven-day period, and litter material was measured from bins, footpaths, street surfaces and SEPTs located in stormwater drain inlets. Footpath litter items were not considered when determining the effect of rainfall due to their surfaces being sheltered from rainfall and associated wash off mechanisms. When only street material is considered, up to 77% of the calculated street items entered the stormwater system during rainfall events. These datas suggest that street wash off is the principal mechanism for transport of gross pollutants into the stormwater system.

2.6.5. GROSS POLLUTANT TRAPS

Gross pollutant traps are defined as treatment devices intended to remove litter, debris and coarse sediments. GPTs have evolved from sedimentation basins. They generally consist of a large concrete-lined wet basin upstream of a weir and a trash rack is located above the weir (Willing & Partners, 1992). Maintenance involves dewatering the wet basin and using a backhoe to remove sediments (Willing & Partners, 1992). Gross Pollutant Traps are primary structural treatment measures for stormwater (CSIRO, 1999). There are several types of pollutants that can enter a waterway. They range from gross pollutants (trash, litter and vegetation larger than 5 mm), sediments (fine (<0.062), medium (0.062-0.5 mm), coarse (0.5-5 mm)), attached pollutants (attached to fine sediments specifically nutrients, heavy metals, toxicants and hydrocarbons) and dissolved pollutants (typically nutrients, metals and salts) (CSIRO, 1999), as well as bacteria, viruses and other organisms, oxygen-demanding substances and aquatic weeds (Dept. of Urban Services, 1992). The nature of the pollutants entering the catchment drainage system is dependent on the land use within the catchment (Smith, 2001). The removal of gross pollutants is generally desirable as they are unattractive, disturb physical habitat, degrade water, attract pests and vermin, cause marine animal deaths, promote littering and reduce amenity (Allison et al., 1998). The NSWEPA, local government councils and Sydney Water have all in recent policy emphasised the necessity for stormwater treatment units in stormwater management (Smith, 2001). It has been suggested that leaching of contaminants such as heavy metals, petroleum hydrocarbons, nutrients and herbicides is taking place within GPTs (Ball et al., 2000). The pollutant load is accumulated under a body of water (as occurs within a GPT) and in conditions of no light, little or no flow, reduced oxygen and low pH, a toxic pollutant load will leach toxicants into the surrounding waters (Abel, 1989). In a storm event these leached pollutants are likely to be flushed into receiving waters in unstable and bioavailable forms. The above processes are heavily influenced by frequency and intensity of storm events, land use within the catchment (Hall & Anderson, 1987), and design and maintenance of the GPT (Allison *et al*., 1998). Sydney Water have found that whilst a GPT caused a reduction in chromium and suspended solids from the upstream to the downstream waters, nitrogen, Total Phosphorus, Biological Oxygen Demand, iron, nickel, copper, zinc, cadmium and lead were increased (Smith, 2001). Different treatments use different processes to remove pollutants, depending on the size range of the pollutant types (CSIRO, 1999). No one treatment can remove all stormwater pollutants. To achieve removal for a range of pollutants a number of treatments are required (CSIRO, 1999). Brookvale Creek catchment utilises the GPT followed by a wetland system downstream to further water quality remediation.

Gross pollutant traps are installed where there is a need for:

- Protecting the aesthetic and environmental quality of small on-line ponds and landscaped drain

- Protecting the macrophysics and fauna habitats at upper ends of water pollution control ponds and urban lakes (Philips & Lawrence, 1990)
- Intercept gross pollutants discharging directly into the sensitive receiving waters (Perrens *et al*., 1990)

Gross pollutants are mainly located at major flood ways and drains to intercept medium to high stormwater flows from large urban catchments. Minor storm pollutant traps are typically small, enclosed GPTs which have been located at the head of the major flood ways, locations where stormwater pipes discharge laterally into flood ways and on the shores of ponds and lakes where stormwater discharges directly into these water bodies (Philips, 1992). There very little reliable data on which to base summaries of expected performance. However, Table 2-9 provides a summary of expected performance, derived from a review of literature by Fletcher *et al*. (2003), along with rationale for these estimates and caveats to be considered in their adoption.

Table 2-9 Summary of Expected Performance for Gross Pollutant Traps

2.6.6. GROSS POLLUTANT TRAP TYPES

Pollutant	Expected removal (mean annual load)	Comments
Litter and organic matter	10%-30%	Depends on effective maintenance, specific design (hydraulic characteristics), etc. 10% where trap width is equal to channel width, 30% where width is 3 or more times channel width
TSS	0-10%	Depends on hydraulic characteristics; will be higher during low flow
TN	0% (negligible)	Transformation processes make prediction difficult
TP	0% (negligible)	TP trapped during storm flows may be re-released during inter-event periods, due to anoxic conditions
Coarse sediment	10-25%	Depends on hydraulic characteristics; will be higher during low flow
Oil and grease	0-10%	Majority of trapped material will be that attached to organic matter and coarse sediment
Faecal coliform	unknown	
Heavy metals	0% (negligible)	

Source: Fletcher et al., 2003

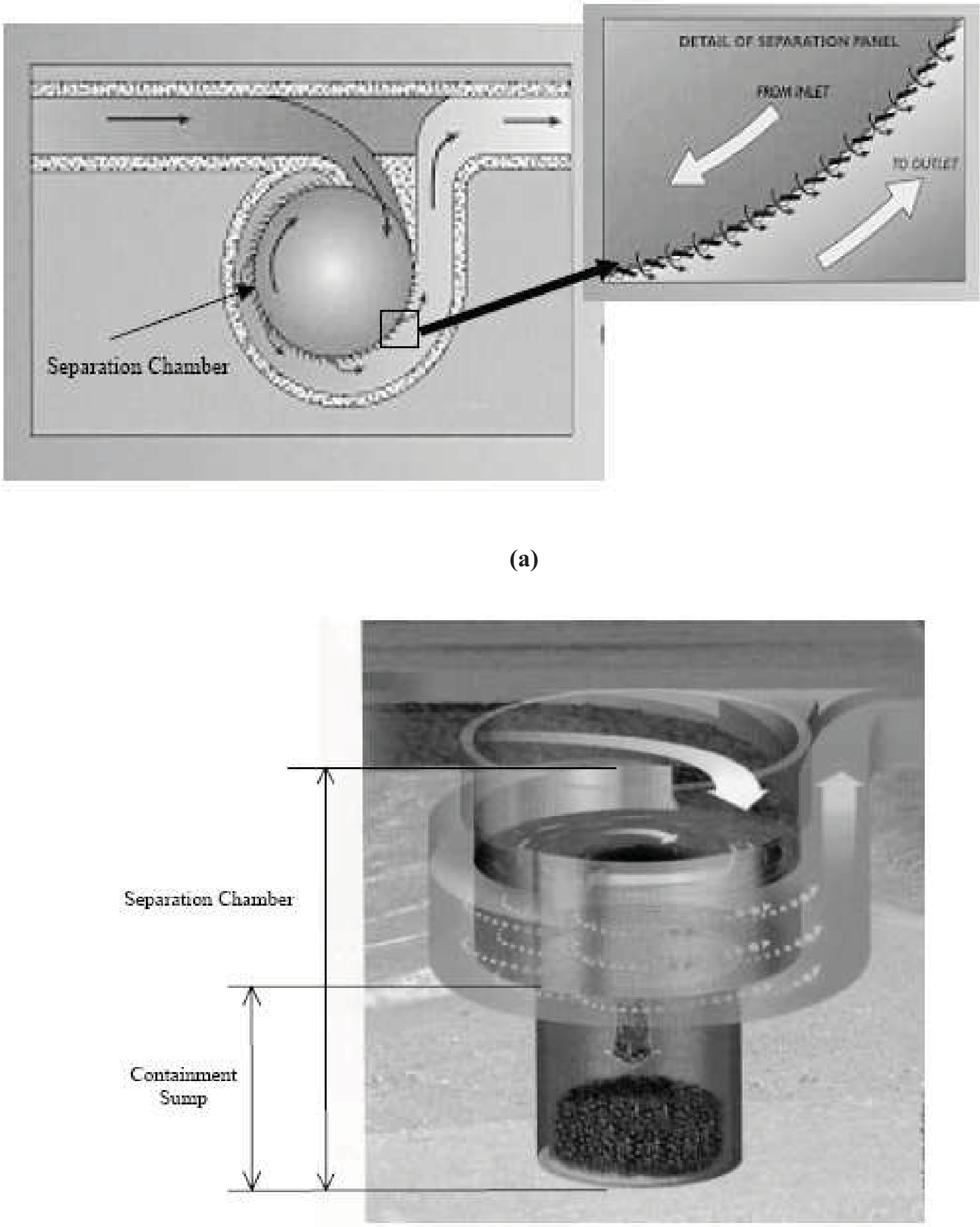
2.6.6.1.WATER QUALITY FILTERS / HYDRODYNAMIC DEVICES

Hydrodynamic separators are flow-through structures with a settling or separation unit to remove sediments and other pollutants that are widely used in stormwater treatment. No outside power source is required, because the energy of the flowing water allows the sediments to efficiently separate. Depending on the type of unit, this separation may be by means of swirl action or indirect filtration (USEPA, 1999). Broad spectrums of best management practices have been designed to remove non-point source pollutants from runoff as a part of the conveyance system. These structural BMPs vary in function, but all utilise some form of settling and filtration to remove particulate pollutants from stormwater runoff, a difficult task given the concentrations and flow rates experienced. Regular maintenance is critical for BMPs. Many water quality filters, catch basin insert and hydrodynamic devices are commercially available. They are generally configured to remove particulate contaminants, including coarse sediment, oil and grease, litter and debris (Pennsylvania Stormwater Best Management Practices Manual, 2006).

2.6.6.2.CDS™

The CDS™ unit is a proprietary stormwater treatment device developed in Australia and is marketed through CDS™ Technologies in the US. They are hydrodynamic devices. CDS devices are gross pollutant traps designed to capture trash and debris and have been found to efficiently trap gross pollutants in urban stormwater. The unit is typically installed below ground requiring an area of between 10–20 m^2, depending on the design operational flow. Maintenance requirements for the device have been reported to be lower than conventional devices that block because of the self-cleansing screen which is a result of the continuous deflective separation mechanism. The mechanism by which the CDS technology separates and retains gross pollutants is by first diverting flow and associated pollutants in a stormwater drainage system away from the main flow stream of the pipe or channel into a pollutant separation chamber as shown in Figure 2.10 a.

The separation chamber consists of a containment sump in the lower section and upper separation section as shown in Figure 2.10 b. Gross pollutants are retained within the chamber by a perforated plate that allows water to pass through to the outlet pipe. The water and associated pollutants contained within the separation chamber are kept in continuous motion by the energy generated by the incoming flow. This has the effect of preventing the separation plate from becoming blocked by the gross solids retained from the inflow. Heavier solids settle into the containment sump and much of the neutrally buoyant material eventually sinks while floating material accumulates at the water surface.



(a)

(b)

Figure 2.10 a) Isometric Representation and b) Schematic Plan View Representation of the CDS System (CDS Technologist, 1998)

Evidence from laboratory studies (Wong *et al*., 1997) and field data (Allison *et al*., 1998) suggests that the device is capable of providing further benefits to stormwater quality by trapping a significant proportion of material that is finer than the screen aperture size (typically 4.7 mm). Allison *et al.* (1998) indicated that 90% of the sediment collected (i.e. excluding other trapped material) in the containment sump of the Coburg CDS unit was less than the 4.7 mm screen size as shown in Figure 2.11. Analysis of sediment contained in the CDS unit was carried out by sieve analysis down to 45 µm. Of the sediments collected, approximately 70% were found to be less than 400 µm in size.

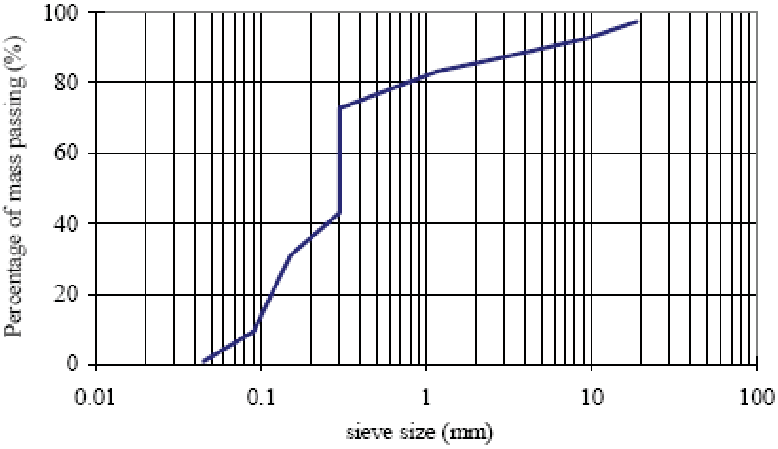


Figure 2.11 Sediment Size Grading Collected from the CDS Containment Sump (Allison *et al*., 1998)

The removal efficiencies for CDS units is a function of particle size and screen aperture size. Stain (1999) at Portland State University conducted a series of tests under laboratory conditions using graded sand and coarse sediment particles with specific gravity of 2.65 for 1.2 mm and 4.7 mm screen apertures. Wong (1997) conducted similar tests to determine the effect of inlet pipe velocity for the unit with screen apertures of 2.4 mm for six sand gradations with mean diameters ranging from 200–780 µm at inlet pipe velocities of 0.5, 1.0 and 1.4 m/s. In both studies, the results of removal efficiencies declined with increasing particle size. The efficiency found was independent from inflow velocities for the tested range (Wong, 1999).

In regard to hydraulic characteristics of the device performance, there are a few studies conducted for CDS units. According to Allison et al. (1998) studies, the headloss values attributed to the CDS unit increased with discharge. The maximum energy loss caused by the device was approximately 0.4 metre and occurred at a flow rate of approximately 550 l/s. The headloss coefficient of the unit is in order of 1.3.

2.6.6.3.CLEANS ALL™

The CleansAll is another gross pollutant trap (Figure 2.12). Currently several CleansAll are being installed by conduction of the Urban Water Resource Centre in the USA. The analysis of pollution captured of organic, litter and sediments were 80%, 10% and 10% respectively. It has been reported that in one of the installations monitored, 90% of the sediments retained in the sump are less than 75 micrometres, while 50% were less than 75 micrometres at another site.

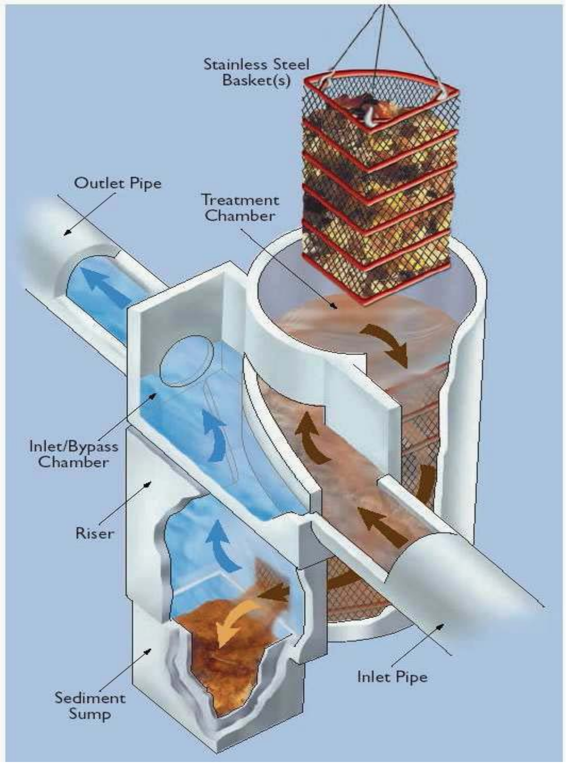


Figure 2.12 CleansAll ™ Gross Pollutant Trap Schematic (Orange County Stormwater Program Trash and Debris BMP Evaluation, 2003)

2.6.6.4.VORTECHS™

The Vortechs is another hydrodynamic separator designed to use stormwater gravitational force to separate litter, and to remove floating items from stormwater flow. The Vortechs system removes finer sediment, particles, free oil and debris from urban runoff. The unique design allows for easy inspection and unobstructed maintenance access. This high-performance system uses an effective combination of swirl-concentrator and flow-control technologies to maximise treatment.

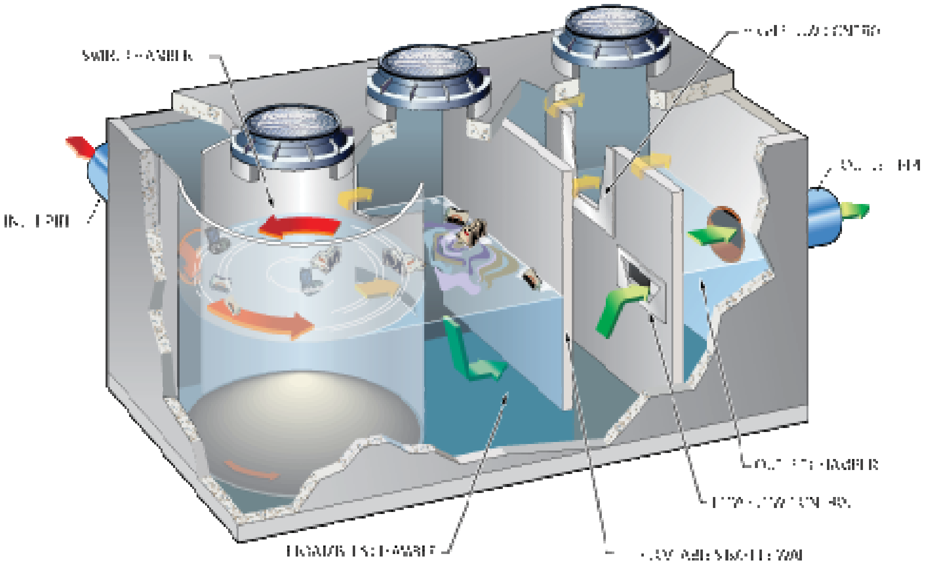


Figure 2.13 Vortech Schematic (Stormwater 360: Vortechs, Stormwater Treatment)

The Vortechs™ Stormwater Treatment System is a patented hydrodynamic separator designed to enhance gravitational separation of floating and settling materials from stormwater flows. The system was developed in Scarborough, Maine in 1988.

The Vortechs™ System is well-suited to urban stormwater applications due to the following features:

- Infrequent flow rates can be treated without bypassing the System due to high treatment capacities
- Below grade installation allows multiple land uses
- Each system is custom-designed to meet hydraulic demands of the site
- Spill storage and sediment storage volumes can be increased as necessary
- Technical support is available at no cost before and after the sale

- No expendable or moving parts and a low cleanout volume minimize operating costs

Independent studies have shown that the system is capable in some cases of reducing the net total suspended solids load exported from a site by 80 percent or more.

The ‘typical gradation’ has an average particle size (d50) of 80 microns, and contains particles ranging from 38–500 microns in diameter (Figure 2.15). This particle range includes medium and fine sands as well as coarse silt. Removal efficiencies of this gradation (Figure 2.14 are used as a basis for sizing Vortechs® Systems when the TSS load is expected to contain a moderate concentration of a wide range of particles (NJCAT Technology Verification Vortechnics, Inc, 2004)

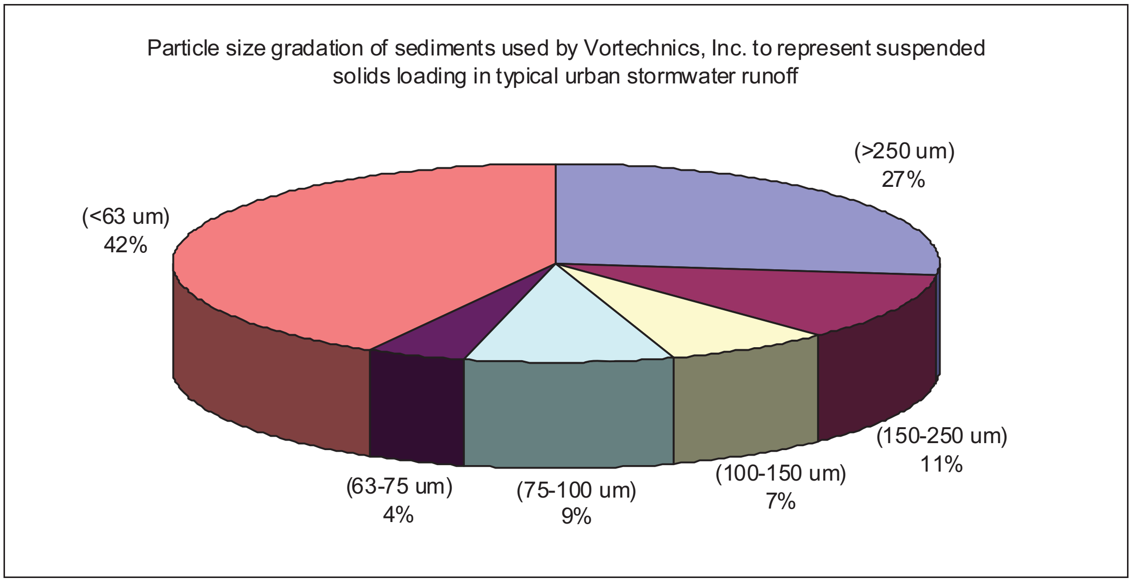


Figure 2.14 Particle Size Gradations of Sediments by Vortechnics, Inc. Representing Suspended Solids loading in Typical Urban Stormwater Runoff

2.6.6.5.SKI-JUMP SILT AND LITTER TRAP

This is a galvanised steel trap that uses screening, flow-separation and energy dissipation to remove litter and debris from stormwater. The screens capture all particles larger than 5 mm. A trash rack inclined towards the flow collects pollutants during low flows.

During large flows, the collected pollutants are pushed downstream into a collection chamber. Several units have been installed in New South Wales. Figure 2.15 shows the device at an installation in Australia. The trap can either be applied to the existing pipe system or built into new works. The best sites for the trap have a drop of 300–400 mm at the pipe outfall to ensure free drainage of the flume and basket and provide a good stilling volume for sediment capture and storage. Installation is possible with a drop of only 100 mm, but with some compromise in efficiency and convenience. An extended, shallower basket is recommended in such cases to raise the floor well above surface water to allow captured material to drain thoroughly and to minimise its decomposition. Accumulation of litter and debris in these systems can be very rapid and greatly reduce the capacity of the device. Consequently, they must be installed at sites with easy access for maintenance crews and their equipment (Orange County Stormwater Program, 2003).

Figure 2.15 Ski-Jump Silt and Litter Trap® (Orange County Stormwater Program, 2003)

2.6.6.6.FRESH CREEK NETTING TRASHTRAP®

Netting TrashTrap® systems capture and remove trash and floatables using the natural energy of the flow to trap trash, floatables and solids in disposable mesh nets. Knotless, knitted mesh nets are manufactured to proprietary Fresh Creek standards. Standard nets are rated for 500 pounds or 25 cubic feet of captured pollutants. A range of special sizes and heavy-duty nets having even larger capacities and handling higher flows and velocities are available. When filled with captured debris, the nets are removed from the system and disposed of in a sanitary landfill. Nets have an opening of either 0.25 inch or 0.50 inch. Figure 2.16 shows a schematic of the device.

There are three types of Fresh Creek Netting TrashTrap®. The In-Line Netting TrashTrap is a concrete chamber containing the structure that holds the disposable bags. This system is located between the regulator and the outfall. The End-of-Pipe Netting Trash-Trap is installed at the end-of-pipe usually at the existing outfall structure. The Floating Netting TrashTrap is a pontoon structure that floats at the end of the outfall.

Accumulation of litter and debris in these systems can be very rapid and greatly reduce the capacity of the devices. Consequently, they must be installed at sites with easy access for maintenance crews and their equipment. Required equipment often includes a crane for removing nets.

The system consists of a structure to hold the framework for the nets. There is also a bypass screen above or below the bags to screen the entire flow in the event of backup. These screens are designed with shear pins for the larger, infrequent events.

Field tests sponsored by U.S. EPA indicate that Netting TrashTrap® technology can provide removal efficiencies of greater than 90% for trash and floatables when properly operated and maintained, (EPA, 1999). Removal efficiencies were determined by the equation:

Removal Efficiency (%) = (Mass retained) *100/ (Mass retained + Mass passing)

Maintenance of the Netting TrashTrap is done by replacing the disposable nets following events where sufficient quantities of floatables have been captured. This is usually determined by visual inspection. In-line and end-of-pipe systems are serviced with a boom truck. This requires a minimum crew of two people. The change-out procedure for one net can usually be completed in 30 minutes.

Floating systems can be serviced in several ways. Skimmer boats can be used for water-based servicing. The full nets are floated out of the back end of the units and are lifted onto the workboat for transport to an off loading facility. Shore-based servicing can be done using a boom truck with sufficient reach.

The used nets are disposed of by transporting them to a licensed landfill. In southern California nets may need to be changed following every storm event, which may be as frequently as 10 to 20 times per year depending on site-specific litter conditions and rainfall conditions. Where floatable volumes are lower, nets should be changed at least once per month to remove captured waste. Disposable nets are intended for single use only for sanitary and economic reasons and for ease of maintenance.

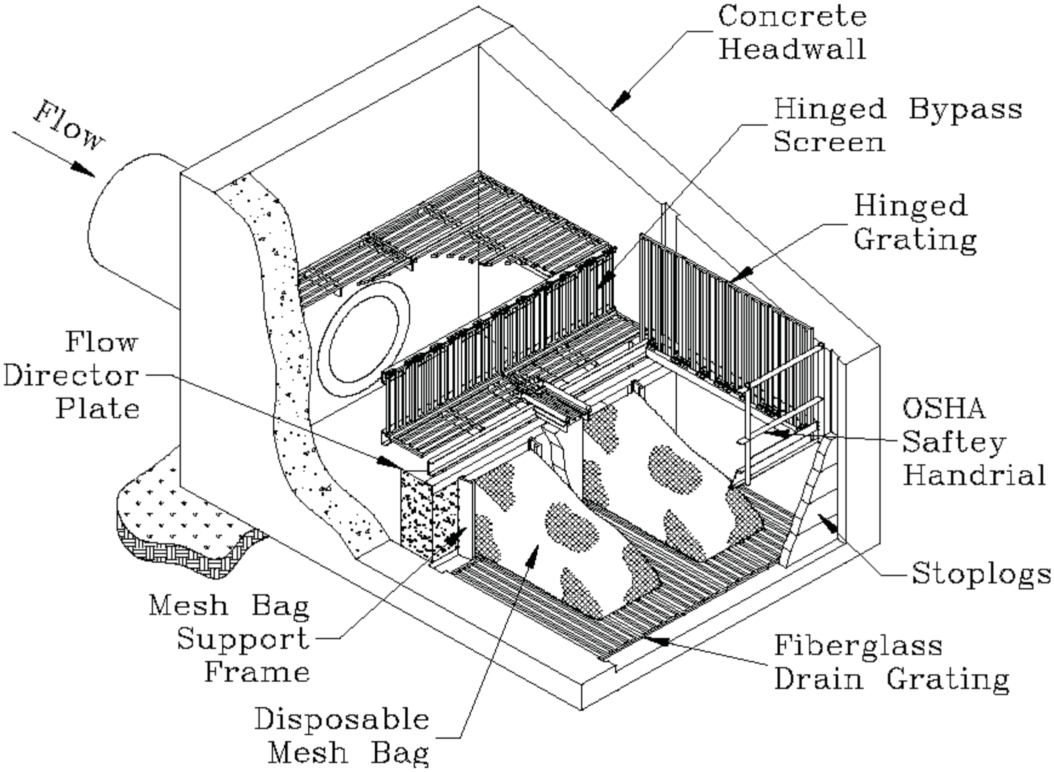


Figure 2.16 Fresh Creek Netting TrashTrap® End-of-Pipe Schematic (Orange County Stormwater Program, 2003)

CHAPTER 3: DIMENSIONAL ANALYSIS

3.1. DIMENSIONAL ANALYSIS

The dimensional analysis is a major part of any experimental fluid flow consideration in order to classify and justify the result. In order to precede this method, we have to start with the law of similarity. This technique is used in every engineering field such as fluid dynamics and thermodynamics where problems with many variables are handled. However the use of this technique may not necessarily be uniform across all engineering fields.

The main fundamentals of dimensional analysis are:

- Being able to determine the dimensions of physical quantities in terms of *fundamental dimensions*
- Understanding the *Principal of Dimensional Homogeneity* and its use in checking equations and reducing physical problems
- Being able to carry out a formal dimensional analysis using *Buckingham's Pi Theorem*
- Understanding the requirements of *physical modelling* and its limitations

Dimensional analysis is a means of simplifying a physical problem by appealing to dimensional homogeneity to reduce the number of relevant variables. The main variable and physical properties are acceleration, velocity, viscosity and energy. So they should be reduced to their *primary of fundamental dimension* together with their SI units. These are:

mass	M	(kilogram, kg)
length	L	(metre, m)
time	T	(second, s)
temperature	θ	(Kelvin, k)

In order to analyse model studies and correlating the results of experimental research, it is essential that researchers employ dimensional parameters.

3.2. HYDRAULIC MODELS AND SIMILARITY

3.2.1. HYDRAULIC SIMILARITY

The use of dimensional analysis is the basis for the physical model design operation and analysis. The physical scale models are designed to predict the real model (prototype) behaviour. The models which are geometrically similar to the real model but in a smaller scale, are used in the design of ships, submarines, aircraft, turbines, pumps, breakwaters, river and estuary engineering work, spillways, etc. (Nalluri & Featherstone, 2006).

Hydraulic similarity laws are used to determine the relationship between model and prototype performance. Because of the variation of the laws, the models usually cannot comply with all of them simultaneously, and the models are not expected to reflect the prototype performance totally. As mentioned before, the knowledge of the similarity is the key issue to predict the performance of the prototype.

The analysed model and prototype should have three major similarities: geometrical symmetry, dynamical similarity, and kinematics similarity.

Geometrical similarity (*shape similarity*): when prototype and model have geometrically similarity. In the other words, the model must physically resemble the prototype with all of the significant features of the prototype being produced to scale in the model. In conducting a model study, a geometrically-scaled model is first constructed. Use of a geometrically-scaled model gives us geometric similitude. By geometrical scaling, we have made the ratio-corresponding lengths in the model and prototype to have the same value everywhere. That is, any length in a prototype is related to the equivalent length in the model via a scale factor of x (e.g. $l_p/l_m = x$).Therefore the area of the prototype will be the model area squared. $A_p/A_m = x^2$. Also the volume of the prototype shall be the area of the model times x^3.

Dynamic similarity (force similarity): where the velocities and forces are scaled as well as the geometry. This requires that the relevant force ratios to be the same in both the model and prototype. This can be accomplished by making all the dimensionless parameters equal in model and prototype. When this is the case, results can be translated directly from model to prototype.

Kinematics Similarity (motion similarity): for any model at a similar point at a similar time, it must reproduce to scale the velocity of flow experienced within the prototype.

For dynamic similarity, the non-dimensional groups should be equal in the model and prototype. The surface tension effects will be negligible in the prototype and its effect must be minimised in a small scale model. Although, the boundary resistance, as reflected in the Re and ε/l terms, and the gravity force are both significant. Open channel models are operated according to the Froude law:

$$Fr_p = Fr_m \tag{3.1}$$

$$(V/\sqrt{g l})_p = (V/\sqrt{g l})_m \tag{3.2}$$

Where l, the length parameter is the depth, subscript m represents the model and p denotes the prototype. x is the commonly used to indicate a scaling factor in model studies.

By considering the gravity is the same in the both model and prototype, therefore the velocity relationship between prototype and model will be:

$$V_p/V_m = (x)^{1/2} \tag{3.3}$$

and the discharge must be;

$$Q_p/Q_m = (x)^{5/2} \tag{3.4}$$

3.2.2. VORTICITY SIMILARITY

The vorticity case is a complicated case compared to the other similarities. In vorticity, the criteria of similarity involves in the fact that there are two phases of air and water involved. That is why neither the laws of formation of vorticity and of velocity distribution in the rotating flow, nor problems of similarity have so far been fully solved (Novak & Cabelka, 1981).

Originally, it was assumed that for fully-developed turbulent flow with a high Reynolds number, it is possible to use the Froude law, especially when velocities and discharges were concerned. This idea was held by Blau, Escande, Camichel and others who maintained that, the velocity scale of the rotating flow is similar to the above velocity equation, (3.3).

It has been shown, however that apart from forces of gravity, viscous forces and to a smaller extent, surface tension, also affect the vortiecities (Novak & Cabelka, 1981).

For example, to determine the relationship between velocities, angular velocities, discharges, and times for a model and a prototype, the following method can be used.

Velocity ratios may be obtained directly from the appropriate modelling parameter (Re, Fr, We or M).

Angular velocity is expressed as a velocity divided by length, and thus:

$$\frac{\omega_m}{\omega_p} = \frac{V_m L_p}{L_m V_p} = (\frac{V_m}{V_p})(\frac{L_p}{L_m}) \tag{3.5}$$

A discharge is velocity times an area, and thus:

$$\frac{Q_m}{Q_p} = \frac{V_m}{V_p}\frac{A_m}{A_p} = (\frac{V_m}{V_p})(\frac{L_m}{L_p})^2 \tag{3.6}$$

Time is the ratio of the length to the velocity, and thus:

$$\frac{t_m}{t_p} = (\frac{L_m}{V_m})(\frac{V_p}{L_p}) = (\frac{L_m}{L_p})\frac{V_p}{V_m}) \tag{3.7}$$

Dynamic similarity exists between geometrically- and kinematically-similar systems if the ratios of all forces in the model and prototype are the same.

When the dimensional analysis method is employed and if the non-dimensional quantities (such as Reynolds number and Froude Number) are the same for both devices, the results of the model device tests are applicable to the full-scale device (Nakayama & Boucher, 1999).

By supplementing the knowledge with the experimental data, an analytic relationship between the groups can be constructed allowing numerical calculations to be conducted (Nakayama & Boucher, 1999).

As mentioned before in this chapter, there are only four fundamental dimensions – M, L, T, and θ. When it comes to dimensional analysis, it is necessary to know for example, that the kinematic viscosity has the fundamental dimensions L^2 T^{-1}. This arrangement applies to other physical properties such as area, volume acceleration and so on. Table 3.1, shows how the dimensions of a quantity can be determined by logical progression from simple to the more complex property of the object.

Table 3-1 Quantity, Common Symbol(s) and Dimensions

	Quantity	**Common Symbol(s)**	**Dimensions**
Geometry	Area	A	L2
	Volume	V	L3
	Second moment of area	I	L4
Kinematics	Velocity	U	LT-1
	Angle	∅	None
	Angular velocity	ω	T-1
	Quantity of flow	Q	L3T-1
	Mass of flow	m	MT-1
Dynamics	Force	F	MLT-2
	Moment, torque	T	ML2T-2
	Energy, work, heat	E, W	ML2T-2
	Power	P	ML2T-3
	Pressure, stress	P, τ	ML-1T-1
Fluid properties	Density	ρ	ML-3
	Viscosity	μ	Ml-1T-1
	Kinematic viscosity	ν	L2T-1
	Surface tension	σ	MT-2
	Thermal conductivity	k	MLT-3θ-1
	Specific heat	Cp, Cv	ML-1T-2

What it is called today as fundamental units were not always fundamental. They were formally named in 1832 by C.F. Gauss (Huntly, 1952). However, it was Newton, in his book Principia (II, Proposition 323) who named three distinct entities as length, inertia and mass. He used these quantities to define all remaining dimensions which are often referred to as secondary or derived dimensions (Brennan, 2002).

3.3. DIMENSIONLESS PARAMETERS

We are interested in obtaining the most significant and independent parameters (so called dimensionless parameters or groups), for the particular physical system being analysed. Actually, the resulting groups will indicate only how to organise a set of experiments and how to plot the resulting experimental data. We cannot determine how one dimensionless variable will vary with another except by experiment (in a few instances of viscous flow this variation may be calculated analytically). These groups of dimensionless parameters that appear so often that they have been given names – quite often the names of the persons who either first introduced them or first used them extensively. They can all be thought of as force or moment ratios, and most of them use the momentum force as the reference force. Table 3.2 below gives some of the most used parameters with their definition and qualitative ratio of effects and the degree of their importance.

Reynolds number, $Re = VD/q = rVD/\mu$ (ratio of momentum forces to viscous forces):

The Reynolds number is probably the most used of all the dimensionless parameters in fluid mechanics, since it is most descriptive parameter for distinguishing the nature of flow of engineering interest. Generally, the Reynolds number is an important parameter in deciding whether a flow is laminar or turbulent—such as in a pipe—and in determining the drag on a solid surface. Typically at low Reynolds numbers, flows are laminar whilst at large Reynolds numbers, flows are turbulent. For example, in pipe flows with D being pipe diameter and V the average velocity, flows with Reynolds numbers less than 2,000 are laminar, while flows with Reynolds numbers greater than 2,000 exhibit various degree of turbulence.

Froude number, $Fr = v\,(gh)^{1/2}$ (square root of the ratio of momentum force to gravity forces):

The Froude number is of particular importance in flows that are affected by gravity, such as wave phenomena. In many references the square of our definition is also often called the Froude number. Because of its importance for waves, it plays a major role in determining that part of the drag of a ship due to the wave produced at the surface.

Froude numbers can be expressed to arise in any problem where free surfaces are present. When the Froude number is very large, gravity forces are unimportant.

Mach number, $M=V/c$ (square root of the ratio of momentum forces to compressibility forces):

For high speed floes, many of the flow characteristics are governed by the Mach number. The c appearing in the definition is the local speed of sound. The Mach number is a deciding factor in deciding whether compressibility plays a role in a given problem. As a rule of thumb, if the Mach number is less than 0.25 or so, the flow can be considered to be incompressible, regardless of whether the fluid is a liquid or gas. Flows in Mach numbers less than 1 are termed subsonic flows, and flows with Mach numbers greater than 1 are termed supersonic flows. The proposed National Space Plane is scheduled to fly at speeds up to Mach 23.

Weber number, $W_e= V^2/r/\sigma$ (ratio of the momentum force to the surface tension force):

The Weber number is of importance in interface problems, such as surface waves or motion of bubbles.

This listing of dimensionless parameters is by no means exhaustive, but it does cover the more commonly encountered ones.

Table 3-2. Dimensional Analysis and Similarity

Parameter	**Definition**	**Qualitative Ratio of Effects**	**Importance**
Reynolds number		Inertia Viscosity	Always
Mach number		Flow speed Sound speed	Compressible flow
Froude number		Inertia Gravity	Free surface flow
Weber number		Inertia Surface tension	Free-surface flow
Cavitation number (Euler number)		Pressure Inertia	Cavitation
Prandtl number		Dissipation Conduction	Heat convention
Ekert number		Kinematic energy Enthalpy	Dissipation
Specific-heat-ratio		Enthalpy Internal Energy	Compressible flow
Strouhal number		Oscillation Mean speed	Oscillating flow
Roughness ration		Wall roughness Body length	Turbulent, rough wall
Grashof number		Buoyancy Viscosity	Natural convection
Temperature ratio		Wall temperature Stream temperature	Heat transfer
Pressure coefficient		Static pressure Dynamic pressure	Aerodynamics, Hydrodynamics
Lift coefficient		Lift force Dynamic force	Aerodynamic, Hydrodynamics
Drag coefficient		Lift force Dynamic force	Aerodynamics, Hydrodynamics

Example of the Use of Dimensionless Parameters

Loss in a pipe:

When fluid flows in a steady fashion through a horizontal pipe of diameter D and length *l*, the dominant forces will be the driving force (pressure), the resistance force (wall shear, or viscous force) and the inertia force. To find the governing dimensionless parameters:

Sought: Dimensionless parameters given two quantities and three forces

Given: The quantities involved are Δp, r, V, *l*, D, *k,* and μ. The first six quantities come from the geometry and the forces as detailed in Table 4.1. *k* is another length quantity, the average height of the roughness in the pipe. The dimensions of the seven quantities are:

$[\Delta p] = F/L^2$, $[\rho] = FT^2/L^4$, $[V] = L/T$, $[l] = L$, $[D] = L$, $[k] = L$,
$[\mu] = FT/L^2$

Assumptions: All quantities of importance to the problem have been included in the analysis.

Solution: Since there are seven dimensionless quantities and three dimensions, there can be at most four independent dimensionless parameters. Forming these parameters from knowledge of the force ratios, we find:

C_p, Re, l/D, and k/D.

If these are the only quantities of importance to the problem, we are thus able to write:

$C_p = C_p\,(\mathrm{Re}, l/D, k/D)$,

A little thought can make this result more informative. Since we are dealing with a situation where all quantities are independent of the pipe length except the pressure difference, and since we could expect that doubling the length should double the pressure difference need to keep the average velocity the same, then

$Cp = (l/D)f(Re, k/D)$,

Where $f(Re, k/D)$ stands for an unknown function of the Reynolds number, and dimensionless roughness.

More commonly, the headloss, $h_l = \Delta p / \rho g$ is used rather than the pressure difference.

Multiplying above equation by V2/2g, we get the result:

$h_l = f\,(Re, k/D)(l/D)\, v^2/2g$.

This is termed the "*Darcy-Weisbach equation*" and is used extensively in analysing pipe-flow problems. The quantity f is called the pipe friction factor, and is a function of the Reynolds number and the relative roughness of the pipe. It must be determined experimentally.

3.4. DIMENSIONAL HOMOGENEITY

The dimensional homogeneity for both sides of any equation must have the same units. Therefore for dimensional homogeneity, both sides of an equation must have the same fundamental dimensions. For example, this concept can be demonstrated by substituting units into a Bernoulli equation to illustrate that all terms could be reduced to metres. Therefore the same result can be achieved by substituting dimensions instead of units into the equation:

$$(p/\rho g) + (V^2/2g) + z = \text{constant} \qquad (3.8)$$

$$\frac{M\,L^{-1}\,T^{2}}{M\,L^{-3}\,T^{2}} + \frac{(L\,T^{-1})^{2}}{(LT^{-2})} + L = \text{constant} \qquad (3.9)$$

$$L + L + L + \text{constant} \quad (3.10)$$

Hence, the constant as can be seen, has the dimension L which is basically the total head expressed in metres. The idea of the dimensional homogeneity is employed in many other equations, for example it is helpful to investigate the units of Manning's n constant or the Chezy's C value. The units rather than dimensions have been substituted into the equations since it is easy and follow same principle.

This method, dimensional analysis can be also used to formulate equations. For example, Einstein's energy equation $E=Mc^2$, Where E is the energy, M is mass and C is the speed of light. Therefore, the dimensional homogeneity gives the answer (Hamill, 2001).

$$E= Mc^2 \quad (3.11)$$

$$ML^2T^2 = M\,(LT^{-1})2 = ML^2T^2 \quad (3.12)$$

3.5. BUCKINGHAM Pi THEOREM

A fundamental but often unsated bit of mathematics that is important to understand from the beginning, is that the units of each and every term in a n equation must be the same. Each term may be made up of a number of different quantities, but the combination that appears as a term in the equation must have the same units as every other term, and must appear as the product or quotient of the quantities. Also, when we use trigonometric, logarithmic, exponential or any similar function that you might be familiar with, we must have that function operating on a dimensionless quantity. Taking the sine or logarithm of units metre or Newton's is *not* a legitimate operation.

The fundamental tool of dimensional analysis is a theorem credited to E. Buckingham that tells us what is possible in a given study. It states that in any physical problem where there are '*q*' quantities (e.g. velocity, pressure, discharge) involving 'd' basic dimensions (e.g. mass, length, time) needed to describe the problem, these quantities can be rearranged into at most (q-d) independent dimensionless parameters. These dimensionless parameters are in the form of product of powers of the q quantities. The dimensions needed to describe most of the incompressible fluid mechanics problems are force (or mass), length and time, and so ‘d’ will usually be 3. In the case of compressible flows it is also necessary to include temperature, so ‘d’ is 4 for these flows.

Usually the words ‘at most q-d’ in the theorem can be replaced by ‘exactly q-d’. In a very few problems, usually those where the number of quantities q is 2 or 3, it may happen that these dimensions always appear in special combinations, so that in fact dimensions can be combined in such a manner so that d is less than 3, giving the need for the ‘at most’ qualification.

Incidentally, the word ‘Pi’ in the name of the theorem has nothing to do with the number 3.14159… Buckingham denoted his dimensionless parameters as $\Pi 1$, $\Pi 2$,…, hence the name.

The proof of the theorem is simple and also provides a means of finding the dimensionless parameters.

3.6. WORKED PROBLEM

In this section by introducing a worked example, we will determine the net force acting on liquid flowing in a pipe.

Suppose that a force F (drag or lift, for example) is believed to depend on several linear dimensions of the system, a, b, c and d; the flow velocity V; the fluid density ρ; the fluid viscosity μ; the acceleration of gravity g; the pressure variation in the system Δp; the fluid surface tension σ; and the fluid compressibility *k*. Then we may write:

$$F = f(a, b, c, d, V, g, \rho, \mu, \Delta p, \sigma, k)$$

There are 12-3 = 9 independent dimensionless groups to be obtained. If a, V, and ρ are chosen as repeating variables, the results of a dimensional analysis are:

$2\Pi 1 = F/\rho V^2 a^2/2$, the drag or lift (or any force) coefficient

$\Pi 2 = a/b$

$\Pi 3 = a/c$

$\Pi 4 = a/d$

$\Pi 5 = \rho Va/\mu$ the Reynolds number Re

$\Pi 6 = V^2/ag$ or $V/(ag)^{½}$ the Froude number Fr

$2\Pi 7 = \Delta p/\rho V^2/2$ the pressure coefficient Cp

$\Pi 8 = \rho V^2 a/\sigma$ or $V/(\sigma/\rho a)^{1/2}$ the Weber number We

$\Pi 9 = \rho V^2/k$ *or* $V/(k/\rho)$ the Mach number M

Thus we may state that:

$\Pi 1 = f(\Pi 2, \Pi 3, \Pi 4, \Pi 5, \Pi 6, \Pi 7, \Pi 8, \Pi 9)$

or that when constants such as 2 are included,

$F/\rho V^2 a^2/2 = f(a/b, a/c, a/d, \rho Va/\mu, V/(ag)^{1/2}, \Delta p/\rho V^2/2, V/(\sigma/\rho a), V/(k/\rho)$

or that,

$C_D = f(a/b, a/c, a/d, Re, Fr, Cp, We, M)$

As mentioned before, it may not be possible to eliminate all but one or two effects in a flow situation, and in these instances, compromises must be made. For example, the drag or lift coefficient may depend on some geometrical parameters and only the Reynolds number in a low-velocity air stream (compressible and gravity effects absent). They may depend on both Re and M in a high subsonic gas flow. They may depend on both Re and Fr for hydraulic flow in a pipe where the velocity of flow is considerable and we deal with free water surface in the pipe.

3.7. SUMMARY OF STEPS IN FORMING DIMENSIONLESS PARAMETERS

The orderly procedure for forming dimensionless parameters can be summarised as follows:

1. Write down the parameters that are important to the problem that you are studying. Make correct decisions by deciding which forces and/or moments are important to your study, and use Table 3-3 to choose the parameters.

2. Select which of the parameters will be repeating variables. The number of repeating variables equals the number of parameters (q) minus the number of dimensions (d). The repeating variables must include all dimensions involved in problem.

3. Write the dimensionless parameter as the product of all of the repeating variables raised to a power.

4. Rewrite the expression written in step 3, this time replacing each parameter by the dimensions of that parameter. Generally, you will use one of force, length and time as the dimensions, or mass, length and time.

5. Collect the powers of the all similar dimensions so that your expression is in the form $F^aL^bT^c$ (or $M^dL^eT^f$). Then for dimensionless parameters to be dimensionless, you will have a series of algebraic equations of the form a=0, b=0, and c=0 (or d=0, e=0, f=0).

6. Rearranging these equations so that the repeating variables are on the right-hand side and the non-repeating variables are on the left-hand side. Solve these equations for the non-repeating variables in terms of repeating variables.

7. Rewrite the dimensionless parameter from step 3 in terms of the powers found in step 6. Collect the terms on the powers associated with each repeating variable. Each of the terms associated with the powers is a dimensionless parameter in its own right.

8. Inspect your set of dimensionless parameters to see if any of them can be easily converted to standard version of dimensionless parameters. (See Section 4.2 on dimensionless parameters.) You may prefer to invert one or more of your parameters, or raise them to a power to eliminate fractional powers, to put them in a more convenient form.

The biggest problem in dimensional analysis is in formulating the list of important quantities that we need to work with. A guide to this formulation is to think about the problem in terms of the basic forces and energies that are of importance to the particular flow case of interest. We are already familiar with basic forces and in dimensional analysis we merely list the terms that are important, and the quantities that are associated with them.

Table 3-3 Representative Forces

Force	Representation
Buoyancy	$\Delta\rho g l^3$
Compressibility	$\rho c^2 l^2$
Drag	F_D
Gravity	$\rho g l^3$
Momentum(inertia)	$\rho V^2 l^2$
Lift	F_L
Pressure	$P l^2$ or $\Delta p l^2$
Unsteady	$\rho \omega^2 l^4$
Viscous	$\mu V l$

CHAPTER 4: PHYSICAL MODELLING

4.1. PHYSICAL MODELLING

In the process of increasing efficiency of the products and at the same time reducing the cost of manufacturing, changes in gross pollutant raps (GPTs) have been initiated in recent years. One of these attempts was focused on modifying the structure of GPTs without compromising the performance or maintenance efficiency of the products. Rocla Pipeline Products is a design and manufacturing company of steel-reinforced pre-cast concrete pipes and gross pollutant traps for several years. They have produced and sold different types of GPTs all around Australia including the Downstream Defender, CleansAll, and many other storm pollutant traps including VersaTraps. The VersaTrap Type A storm pollutant trap which its scale model is used in this experiment, is a structural device located underground within storm drainage lines to remove pollutants from runoff water and stormwater in order to reduce or prevent the contamination of rivers, lakes and other receiving bodies. This type of VersaTrap has been designed especially to allow for bypass flows during high intensity storm events (Rocla Pty. Ltd., 2004).

The Rocla Pipeline Products Company produces mainly three types of VersaTraps called: Type A VersaTrap which is an off-line type GPT, Type G which is basically an in-line type of GPT and Type W which is an industrial-type pollutant trap designed to treat flows from industrial waste water. The VersaTrap Type A configuration provides specific opportunities to suit the customised requirements of the site conditions. The in-line type of GPT has been developed outside of the scope of Rocla's CleansAll range.

In August 2005, Rocla Pipeline Products Company sponsored Curtin University of Technology to test its off-line SPT series A trap for its hydraulic characteristics and pollutant-removal efficiencies. This type of SPT in its standard mode with a relatively simple modification is available to ensure that specifiers and end users are getting the most out of the device according to their specific requirements.

4.2. DESIGN AND OPERATION

The VersaTrap series A is designed for removal of sediments, suspended solids and floatables from stormwater and to prevent re-entrainment of the aforementioned contaminants. Even though some of the chemically-dissolved materials such as nutrients and heavy metals may be trapped by adsorption to fine sediments and debris, the quantities removed by a GPT are generally not significant when balanced against the nutrients released by decomposition of trapped organic matter, unless removed frequently (Rocla, 2004). VersaTrap models essentially consist of two coaxial cylindrical chambers as shown in Figure 4.1.

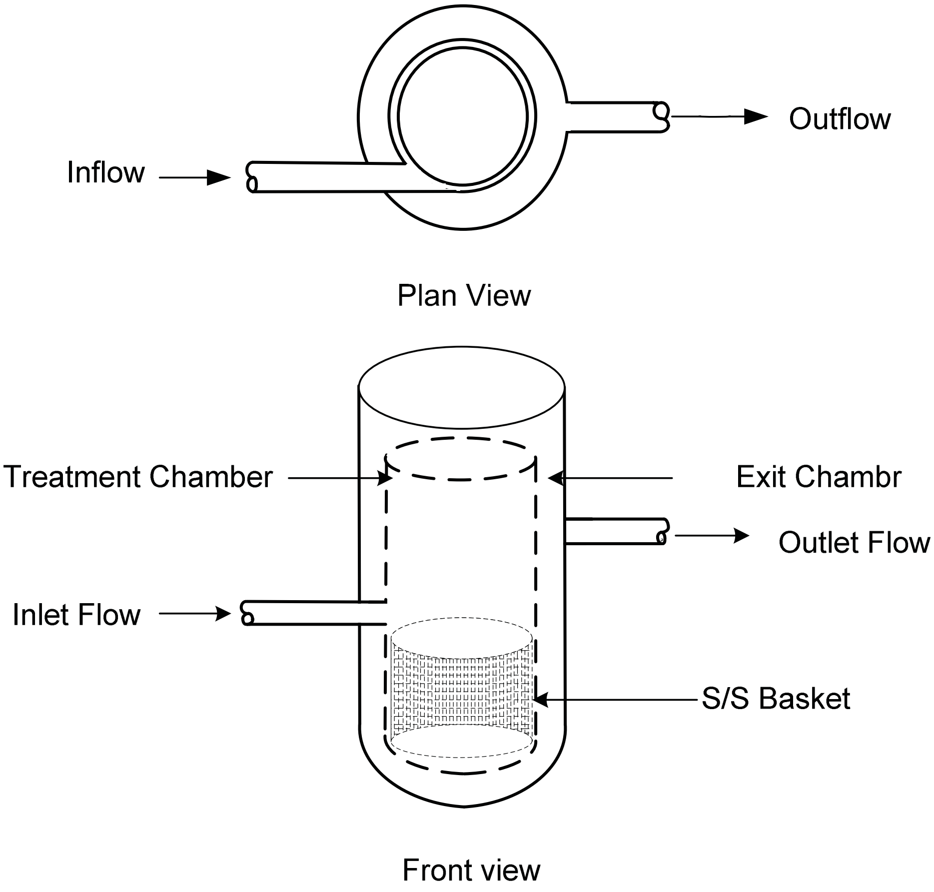


Figure 4.1 Schematic View of VersaTrap Type A

For the purpose of this experiment a VersaTrap series A scale model with outer cylinder diameter of 850 mm and height of 890 mm and inner cylinder with diameter of 312 mm and height of 750 mm were assembled together. A stainless steel basket with diameter of 304 mm and height of 225 mm and 5 mm perforation was placed inside the internal chamber. The inlet and outlet pipe with a diameter of 100 mm were connected to both the internal and external chambers. The inlet pipe crossing through the external chamber was tangentially connected to the internal chamber (for more details refer to Physical Models in Appendix B).

The vortex phenomenon is used to remove pollutants from stormwater entering the SPT. The vorticity of the flow removes pollutants by directing the flow tangentially into a cylindrical container (internal cylinder). The only required power to run the unit is the gravity through the vortex separator depending on the available hydraulic head.

4.3. DESIGN TREATMENT FLOW (DTF)

DTF of VersaTrap Type A: Stormwater pipelines are generally designed to carry the peak flow from a storm event of average reoccurrence interval (ARI) of up to ten years. The ARI depends on several factors such as the outcomes of flooding. A huge number of gross pollutants is carried through the stormwater pipeline system during the first flush of any storm event. The E.P.A. of New South Wales has proposed the effective treatment of 0.25 QI (where QI is a peak flow one year ARI event), is appropriate for the capture of the majority of stormwater pollutants. The VersaTrap range was designed based on 0.3 QI.

Figure 4.2 Internal Basket of SPT Type A

Optimum operating efficiency of SPT is called design treatment flow. It is very obvious that the stormwater flow fluctuates during the day, so the DTF is generally accepted as an average flow during the period of operation. This definition provides guidance as to the size of the unit required.

4.4. DESIGN PEAK FLOW (DPF)

DPF of VersaTrap Type A: is the maximum flow through the unit when a bypass flow occurs. The DPF of SPT Type A depends on the stormwater intensity and it is designed around 13.3 L/s for VersaTrap Type A model.

Some of the criteria used for detailed design of gross pollutant traps are as follows:

i. The gross pollutant trap's shape and location does not affect the increase in flooding upstream.
ii. The gross pollutant traps shall prevent any additional surcharge in the stormwater system in case of partial or full blockage.
iii. The efficiency of the trap shall not be less than 70% for sediments larger than 5 mm in diameter and retain 100% of all litter and debris greater than 10 mm for all storms up to a six month ARI event.
iv. The sediment traps should not be deeper than 6.5 metres to enable removal of sediment by educator trucks.
v. The pollution reduction performance of a SPT shall be maintained up to the design peak flow. If design peak flows are exceeded, the GPT shall not allow any significant remobilisation of the trapped rubbish.
vi. The GPT shall be designed for easy maintenance and occasional inspection between clean outs.

The above mentioned criteria are similar to those specified on other projects by Willing and Partners, 1988, Fox and O'Brien, 1992.

4.5. BYPASS CAPACITY

The SPT should be equipped with a facility to bypass flow in excess of treatment discharge during storm events of greater intensity. The VersaTrap series A are equipped with an upstream diversion weir pit which diverts excess flow back to the main stream.

4.6. THE BASKET

The basket of the SPT has a double duty. Firstly, to capture maximum rate of gross pollutants, and secondly, to allow them to be removed easily and with no confined space access requirements, providing very low maintenance and life cost-effective GPTs. The Rocla VersaTrap Type A has a stainless steel basket with approximately 500 µm perforation, allowing the bypass of fine sediments and materials. The screen size and depth are usually designed to suit specific performance requirements.

4.7. BASIC PRINCIPLES

Rocla VersaTraps are hydrodynamic separators of the settling materials and floatable pollutants from stormwater flow. Although the design and size of the models are varied, they still use the same mechanisms for capturing pollutants. Stormwater enters the unit tangentially to the treatment chamber which promotes a gentle swirling motion. As stormwater revolves in the internal chamber, pollutants migrate toward the centre of the unit where the velocities are lowest. The majority of settled or suspended solids and sediments are left behind while stormwater exits the treatment chamber through screen apertures of the basket to the external chamber. Stormwater then exits from the system to the downstream pipe through the external chamber. Buoyant debris is separated from the water by floating on the top of the water surface inside the treatment chamber. Stormwater then exits from the system to the downstream pipe through the external chamber. The flowing stormwater at this stage is relatively free of floating pollutants. The main difference between this type of separation method and conventional screening lies in the indirect nature of the screening process, whereby the flow is dissipated in a controlled way through the screen and hence, blockage is avoided. Floatable and other collected debris stay above the level of inflow in VersaTrap units and hence are protected from disturbance and re-entrance to the main flow subsequently. Suspended solids are collected in a circular stainless steel basket which sets into lower level part of the treatment chamber. By tangential flow of the inlet flow and vortex phenomenon, screen blockage by migrating impurities towards the middle of the basket (where the velocity is the lowest), is prevented.

While most of the solids are deposited in the centre of the circular treatment chamber, the fine sediments—with sizes smaller than basket aperture size—are trapped within the settled layer of the litter. The possibility of the finer sediments passing through the screen and being collected by the external chamber—where collection is classified or rated based on particle size and specific gravity in accordance with the limits—is shown in Figure 4.3. Dissolved nutrients and heavy metals absorbed by fine sediments may be removed under a regular and frequent maintenance regime (Rocla, 2004).

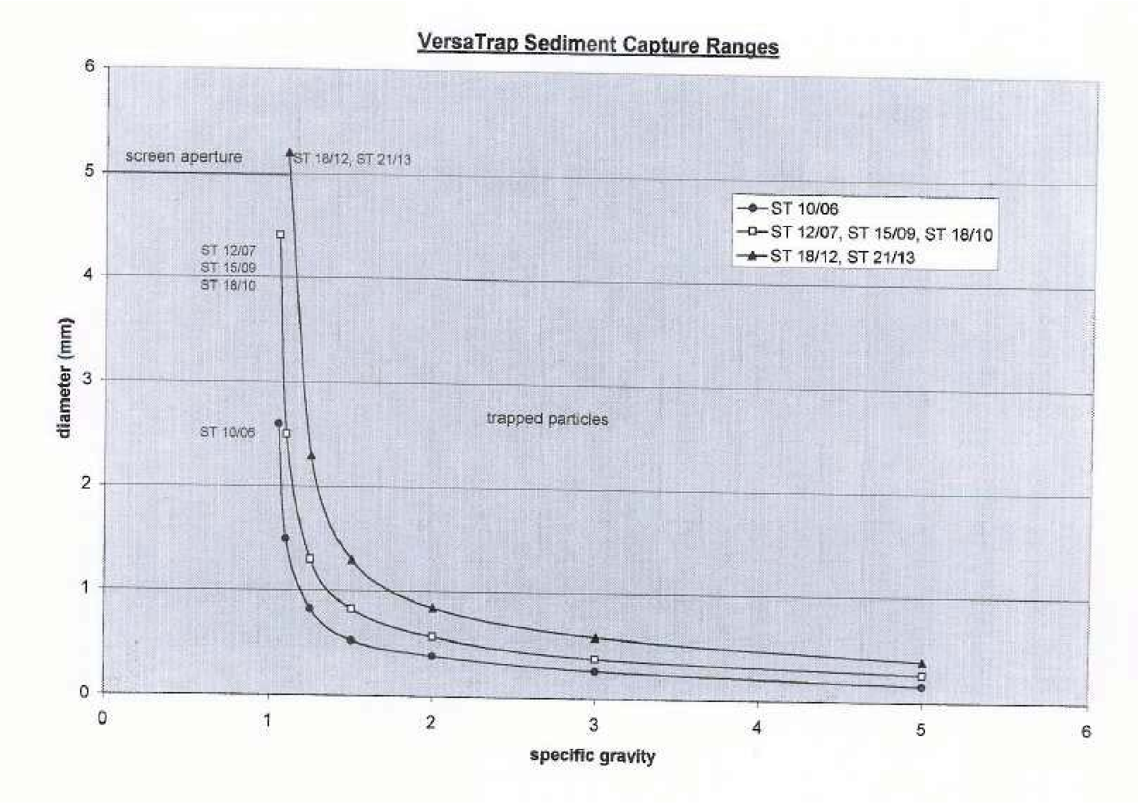


Figure 4.3 Sediment Capture Ranges of VersaTraps (Hepburn, 2006)

4.8. MODIFICATIONS OF THE ROCLA VERSATRAP

The VersaTrap storm pollutant traps are manufactured from a standard spun circular reinforced concrete product and may be modified in many different ways at a minimum cost to achieve performance objectives (Rocla, 2004).

Performance improvements: Two main ways of improving the storm pollutant trap are increasing storage capacity of the trap and providing a deeper basket. Increasing storage capacity is achieved by manufacturing wider and deeper outlet chambers to hold more flow and providing deeper baskets to increase sediment capture efficiency. Increasing the diameter of the exit chamber and providing sediment storage below the treatment chamber is also a way of increasing the storage capacity.

Flooded Outlet: for situations where the outlet is submerged, an in-line device is often unsuitable due to bypass weir height limitations. In these situations a specially designed dual intake storm pollutant trap Type A may be appropriate, combined with a diversion weir pit with double off takes, one located at the base of the weir to collect sediments and the other at the top of the weir to accumulate floatable pollutants. This type of the arrangement prevents deposition of the sediments at the base of the weir and floatables going over the weir.

Multiple connections: the VersaTrap may be configured with multiple inlets, allowing for connections from more than one pipeline or multiple outlets (to increase the mixing efficiency of a biological filter or wetland).

Infiltration: modification to the VersaTrap also can be achieved by incorporating an aperture in the base of the treatment chamber allowing for in-line infiltration with water-sensitive urban design principles.

4.9. SPECIFICATIONS OF THE ROCLA VERSATRAP

To improve a stormwater pollutant trap, it is generally specified that floatables, litter and sediments require removal before discharging the trap into a receiving body of water (which may be a retention pond or other pollutant reduction system). Each case is unique in terms of parameters such as pipeline diameter, flow rate, depth, velocity, groundwater level and pollutant level. The Rocla VersaTrap Type A is designed to trap pollutants from stormwater such as leaves, twigs and sediments from residential areas. Its capacity varies from 32 L/s treatment flow up to 350 L/s and storage floating up to 442 litres. The performance specifications for standard VersaTraps are given in Rocla VersaTrap Specification 1, Appendix B.

4.9.1. HEADLOSS

The introduced headloss for VersaTrap stormwater pollutant traps get critical only when the design peak flow at maximum bypass occurs. In a worse case scenario, it is appropriate to consider the total blockage of the VersaTrap storm pollutant trap. Headloss across VersaTrap Type A is calculated based on the following:

- For the VersaTrap Type A, the energy loss coefficient is obtained from sum of the coefficients for a circular pit, the basket assumed half-full and the exit chamber $K_e = 1.5$.

This coefficient is applied to the flow velocity in the outlet pipe to establish the total theoretical headloss across each apparatus. Laboratory testing of model units is used to determine hydraulic characteristics including flow capacities, capture efficiencies and headlosses.

4.10. HYDRAULIC DESIGN

Hydraulic losses through the VersaTrap units vary significantly, mainly due to SPT characteristics such as overflow weir height and capacity of the diversion pit. Hence the VersaTrap designers provide hydraulic design checks of all systems prior to installation, to investigate the upstream effects of installing the unit (SWO, 2003). The gradient of the pipes in the design of the VersaTrap range of GPTs with hydraulic capacity for both treatment chamber and bypass flow are based on 1% gradient. Discharge Flow vs. Hydraulic Gradient Chart shown in Appendix B provides a typical hydraulic design chart for reference purposes. This chart uses the Colebrook-White formula with k = 0.15 mm for circular pipes flowing full. For flatter gradients where larger pipes are required, the

VTA—which is basically an off-line range—is recommended. For steeper gradients, where design flows may be higher, it may be necessary to use a large unit than indicated (Hepburn, 2006).

4.11. INSTALLATION

Installation of a VersaTrap stormwater pollutant trap is very easy and does not need sophisticated procedures. It can be easily installed in parking or fully-developed areas, as they do not require additional space (Hepburn, 2006). The only consideration is maintenance cost. They have been designed for simple and fast installation. A VTA storm pollutant trap is supplied generally as a single complete unit incorporating inlet and outlet pipe connections. It is lifted up to the position and backfilled to the underside of the pipe connection stubs for pipeline connection. Where lifting equipment capacities are limited in some areas, it may be supplied in several parts for assembly on-site. The relatively small footprint area of the VersaTrap is particularly advantageous in areas of high watertable where dewatering is required during the installation process (and sand where boxed excavations are used). Onsite modifications to the height of the VersaTrap may be easily achieved using standard off-the-shelf precast concrete pit sections (Hepburn, 2006).

Gross pollutant traps may be incorporated in stormwater piping systems at the design stage in which case they are installed at the same time as the pipeline carrying the flow to be treated. In many cases, GPTs are required to be installed in existing pipelines.

In cases of installations of GPTs to existing pipelines, temporary diversion and relocation of adjacent pipes is required, causing some disturbance to the operation of the system. Off-line SPTs can be installed with minimal interface to existing pipelines, often using existing junction pits as diversion weir constructions. In cases where existing structures cannot be used, off-line devices with a diversion weir pit are required, meaning a larger overall ‘footprint’ area than an equivalent in-line pipe (Hepburn, 2006). The installation of a diversion weir pit is much easier and less disruptive being shallower and requiring no pipe relocation work. Typical off-line Pollutant Trap Types G and A and their layouts are shown in Appendix B.

4.12. INSPECTION AND MAINTENANCE

The effectiveness of any maintainable device depends on the regular maintenance and inspection of the device. This is true for SPTs also. For best effectiveness and efficiency, they should be inspected and emptied regularly. Regular inspection during the first few months of operation will provide a guideline as to the required frequency of cleaning. Basically GPTs are cleaned by a vacuum pump or by lifting and empting the stainless steel basket into trucks for disposal in landfills (Figure 4.4). Occasionally education of basket type units may be necessary to remove sediments passing through the basket. A fixed circular stainless screen is standard for situations where vacuum eduction is the preferred maintenance method. A removable basket can be substituted where eduction facilities are unavailable or expensive. Long term savings depend upon the fast and easy removal and cleaning of the basket.


(a) (b)

Figure 4.4 Emptying the Basket from a VersaTrap. (a) Eduction Method (Allison *et al*., 1997). (b) Removable Method (Rocla Pty. Ltd., 2002)

Gross pollutant trap type, environmental location and conditions determine maintenance frequency. One way of reduction in maintenance frequency is achieved by increasing storage capacities for the various pollutants by modifications to chamber and screen depths and diameter. In order to achieve the best performance it is recommended that sediment be removed when they reach the depth shown on the specification.

4.13. INSTALLATION AND MAINTENANCE COSTS

Cost comparison for different size and geometry of the several manufactured separators suggests that local conditions such as groundwater levels and type of site may affect the cost-effectiveness. The larger the GPT, the higher the cost of installation and maintenance, including pollutant removal (with associated labour cost, hire of special trucks and equipment). The installation cost of the units are site-specific related, depending on the need to relocate utilities, working space and depth of installation, but are typically approximately half to equal of the unit's cost, which are generally in the order of 50–100% of the manufacturer's cost (Chrispijn, 2004; California Stormwater BMP Handbook, 2003). The installation cost of the Vortices system ranges from 30% for smaller units and 50% for the larger units can be estimated against unit cost (Krahforst *et al.*, 1999).

Maintenance and disposal costs should be considered as a primary consideration when locating and sizing treatment measures, to ensure that maintenance costs will not place an unreasonable burden on council founds in the future (Kidd & Wainwright, 2004; SWWO, 2003).There are several independent studies of the comparative maintenance and disposal costs including cleaning and disposal of both fixed and removable baskets.

4.14. MAINTENANCE EQUIPMENT REQUIREMENTS

- Is special maintenance equipment required? e.g. large cranes, vacuum trucks or truck-mounted cranes. Does this equipment need to be bought or hired – at what cost?
- Is special inspection equipment needed (e.g. access pits)?
- Are any services required (e.g. wash-down water, sewer access)?
- Are there overhead restrictions such as power lines or trees?
- Does the water need to be emptied before the pollutants – if so, how will it be done, where will it be put and what will it cost?
- Can the device be isolated for cleaning (especially relevant in tidal areas)?

For more information about unit selection and costs, refer to Appendix A.

4.15. DISPOSAL COST

Disposal costs will vary depending on whether the collected material is retained in wet or dry conditions (i.e. either underwater or left so it can drain). Handling of wet material is more expensive and will require sealed handling vehicles.

- Is the material in a wet or dry condition and what cost implications are there?
- Are there particular hazardous materials that may be collected and will they require special disposal requirements (e.g. contaminated waste – what cost implications are there)?
- What is the expected load of material and what are the likely disposal costs?

Loads can be estimated using the decision support system developed by the CRCCH (see references) which requires rainfall and land-use information. In the event there is no other data, the values in the following Table should be adopted for Melbourne conditions. Note that litter and gross pollutants (litter and vegetation) are listed, this is because the disposal costs are dependent on the gross pollutant load rather than just the litter component. No litter traps can distinguish between litter and organic material and therefore, in order to remove litter they must also collect debris in the same way.

Gross pollutant loads should be used to estimate disposal costs.

TABLE 4-1 Approximate Litter & Gross Pollutant Loading Rates from Australia

LANDUSE TYPE	LITTER[1] Volume (Litre/ha/year)	LITTER[1] Mass[2] (kg/ha/year)	GROSS POLLUTANTS[3] Volume (Litre/ha/year)	GROSS POLLUTANTS[3] Mass[2] (kg/ha/year)
Commercial	210	56	530	135
Residential	50	13	280	71
Light-industrial	100	25	150	39

[1] litter is defined as anthropogenic materials larger than 5 mm
[2] mass is a wet mass, i.e. the mass expected when removed from a litter trap
[3] gross pollutants contain vegetation as well as anthropogenic litter (not sediments)

The main factors that should be considered for maintenance costs are;

- The relatively short time taken to remove the basket, empty it and replace it. The vacuum eduction process is relatively slow, especially if there is any inflow at the time
- Truck hire rates are relatively low compared to vacuum eduction equipment where usually a minimum hire period applies
- Eduction cost is usually higher if a large volume of liquid is involved compared to the cost of solid waste removal
- GPTs incorporating a removable basket can be maintained at any time, comparing to vacuum eduction which demands zero or very low inflow during the process. This may cause delay in maintenance operation during wet weather
- Fixed screen involves a more complex process compared to removable basket which can be totally cleaned just by a water jet, prior to replacement
- Minimising the number of outlets to rivers or receiving bodies will minimise maintenance cost associated with the installation of GPTs

CHAPTER 5: EXPERIMENT PROCEDURE

5.1. EXPERIMENT PROCEDURE

The set of experiments testing the Rocla VersaTrap (using a scale model) was performed in an open hydraulic laboratory environment at the Curtin University of Technology in Western Australia. The scale model was tested for its hydraulic characteristics and pollutant removal efficiency (PRE). The test procedure was divided into three main sections; the hydraulic test procedure, the PRE test procedure and the diverted pit trap weir procedure. All three procedures will be explained in detail in this chapter.

5.2. EXPERIMENTAL SETUP

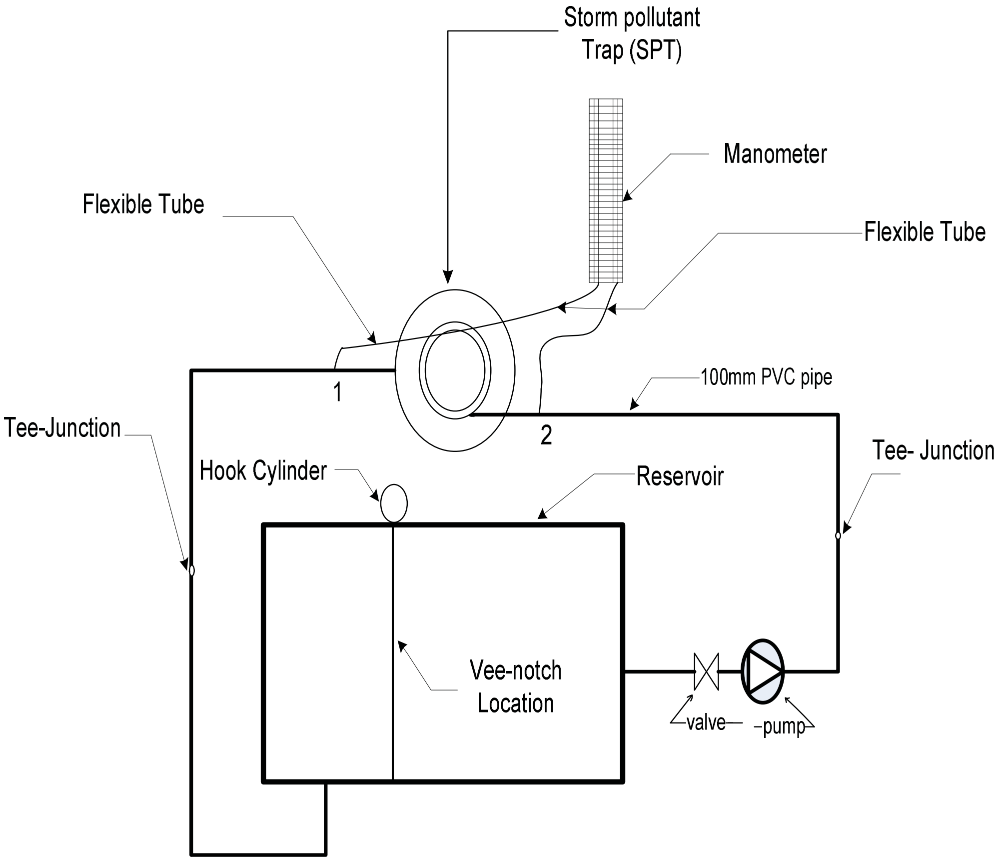


Figure 5.1 Schematic Diagram of the Experimental Setup

In this part, the system was tested with a 0% blocked screen, and then increased to a 22% blockage and after that, adding 10% increments until we reached a 77% total blockage of the screen. The main reason for limiting the state of blockage to 77% in this test is that the published performance data for the VersaTrap Type A (VTA) is stated as applying to a 50% screen blocked condition, and it is recommending that cleaning be carried out at or before this stage is reached. The actual data which was used, however, is as measured in the laboratory at 75% blocked, which provides a reasonable factor of safety.

The inlet pipe to the storm pollutant trap is connected to the inner cylinder of the trap (which is called the active or treatment chamber) at a tangent, creating a vortex inside the basket. Treated water then passes out of the SPT via the outer cylinder (which is called the external or exit chamber) shown in Figure 5.2.

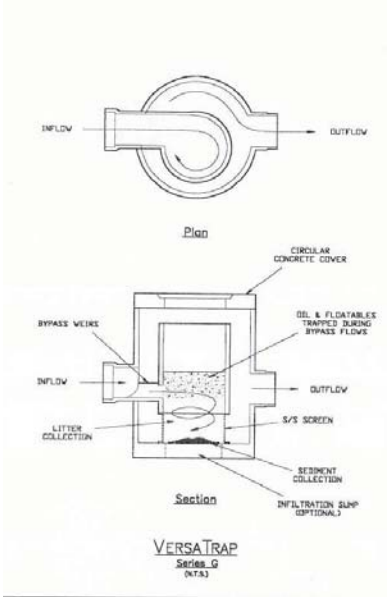


Figure 5.2 Storm Pollutant VersaTrap Type A

The water flow was created in the laboratory model by a base-mounted centrifugal pump capable of circulating up to 14 l/s of flow in the piping network. The pump was connected to the reservoir which is equipped with a 90^{O} V-notch and an attached hook gage weir box measuring the water level above the V-notch. The pump and reservoir connected to a scale SPT model network via a valve and PVC pipes, tees and elbows, pumping through the SPT and sent back to the reservoir to be discharged. Two piezometer tubes were installed on the pipe at sections 1 and 2 (Chow, 1988). This part of the experimental work included subsequent processing covers;

- Pollutant samples
- Parameters

5.2. POLLUTANT SAMPLES

Stormwater pollutant originates from many different sources and types of material, ranging from tree leaves and shrubs up to pollutants with chemical components such as automotive coolant, fuel and oil leakage from vehicles, and includes sediment from building sites. There are mainly three sources of stormwater pollution:

- ➢ Natural pollution, including leaves, garden clippings or animal faeces
- ➢ Direct human pollutant, including cigarette butts, food wrappers, cans, and paper or plastic bags
- ➢ Chemical pollution, including fertilisers, oil and coolant from vehicles, and detergents

In CRC research studies, organic material—leaves, twigs and grass clippings—constituted the largest portion of gross pollutant load (by mass) carried by urban stormwater (Figure 5.3).

Figure 5.3 Gross Pollutants Mainly Comprise Plant Matter

(Source: Allison *et al*., 1997)

This was observed across all urban land-use types. Allison et al., (1997) reported that the potential total phosphorus and total nitrogen loads from vegetation in stormwater are about two orders of magnitude lower than the loads measured in stormwater samples. However, because of its large volume, plant matter should be taken into account in the design of gross pollutant traps, particularly where they could cause pipe blockages or habitat destruction. Most of the litter analysed—by mass and frequency—comprised paper and plastics. These enter the drainage network as street litter from mainly commercial areas. Large quantities of food, drink and cigarette refuse were also found during the monitoring (see Figure 5.4).

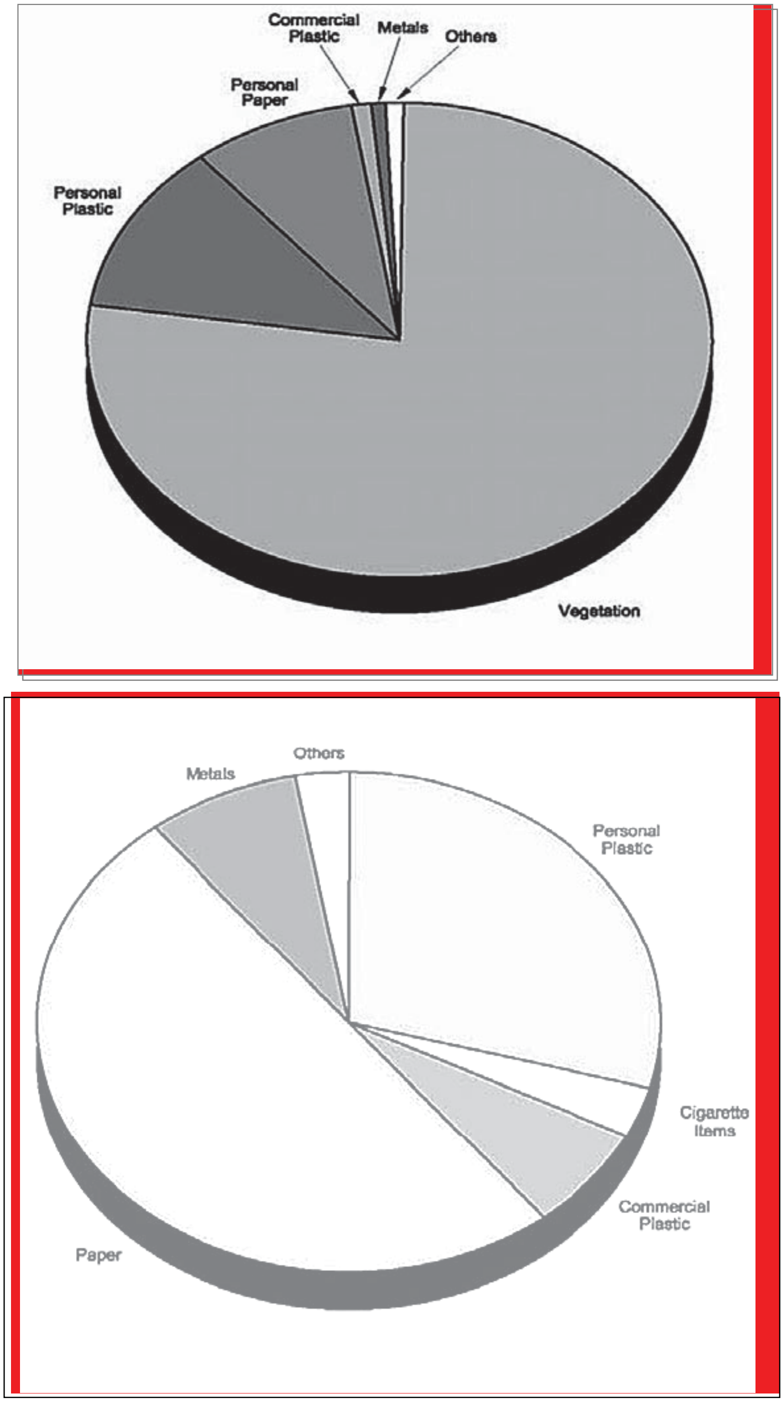


Figure 5.4 Composition of Urban Gross Pollutants by Litter and Mass

(Source: Allison *et al*., 1997)

These figures suggest that fast food consumers and smokers are a significant source of litter in urban streams.

5.3. PARAMETERS OF FLOW MEASUREMENTS – "HYDRAULIC CHARACTERISTICS"

All hydraulic characteristic tests were performed with the scale model. One of the most important parameters in this experiment, which is headloss, was measured and calculated at every flow rate for the VTA model at seven different screen conditions: 0, 22, 33, 44, 55, 66 and 77% screen blockage.

The flow rates in laboratory tests were up to 13.3 L/s. The screen size for this experiment was 5,000 µm.

5.4.1. VELOCITY HEAD AND PRESSURE HEAD

Manometers are a common device usually used to measure head flow of differential heads in a U-tube. The pitot tube as shown in Figure 5.5, provides a means of measuring the velocity at a point either inside the pipe or in an open channel. Essentially, a pitot tube measures the velocity head, which is the dynamic pressure of the flow at one point by turning the kinetic energy into the equivalent static head of liquid, H (Hamill, 2001).

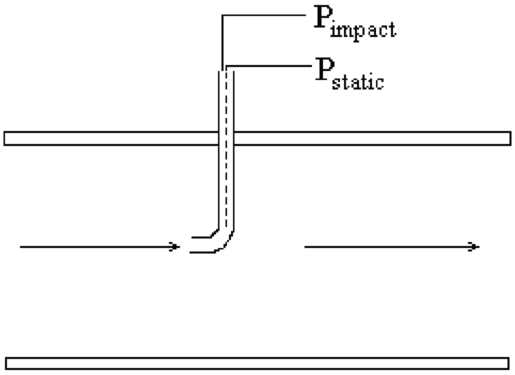


Figure 5.5 Pitot Flow Meter

[From: http://www.pc-education.mcmaster.ca/instrumentation/flow.htm]

The velocity gradient that exists throughout the flow cross-section is generally represented at the flow's surface – essentially creating a 'finger-print' of the velocity contours that exist below the surface. Figure 5.6 depicts the relationship that exists between various velocity contours and the mean velocity at different depth/diameter ratios. Therefore the fluctuation of the manometer which appeared during the flow measurement mainly depended on the velocity of the flow below the surface of water.

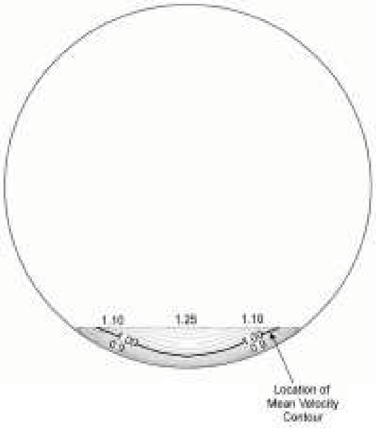


Figure 2a:
d/D= 0.10

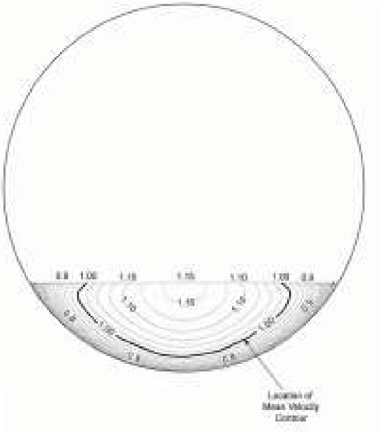


Figure 2b:
d/D= 0.25

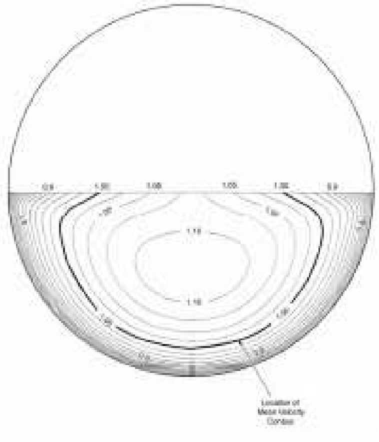


Figure 2c:
d/D= 0.50

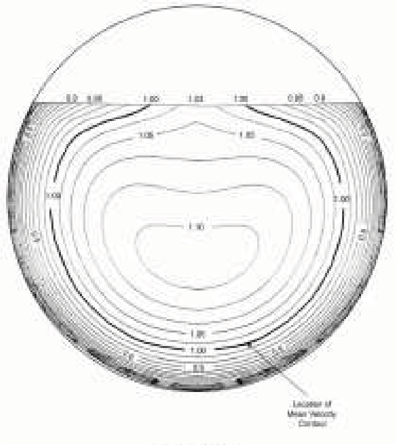


Figure 2d:
d/D= 0.75

Figure 5.6 Relationship Between Various Velocity Contours and Mean Velocity
(From: *Understanding the Flo-Dar Flow Measuring System*, Marsh-McBirney Inc, 2005)

5.4.2. FLOW RATE MEASURING DEVICES

The measurement of the flow in a pipe or open channel can be measured by using different measuring devices such as Venturi meter, an Orifice plate, nozzles, an Elbow meter, a positive displacement meter, a rotameter, a magnetic flow meter and weirs. In this experiment a weir was used as a measuring device of flow in the pipe passing through the storm pollutant trap. Weirs are simple and reliable devices for measuring steady flows in open channel flow. A weir is an obstruction across a channel, usually a plate with a cut-out area, over which the liquid flows (Graebel, 1999). A V-notch weir is shown in Figure 5.7. The notch sizes of 90, 60, 45 degrees – all of which are very common. A 90 degree V-notch weir was used in this experiment to measure the flow rate.

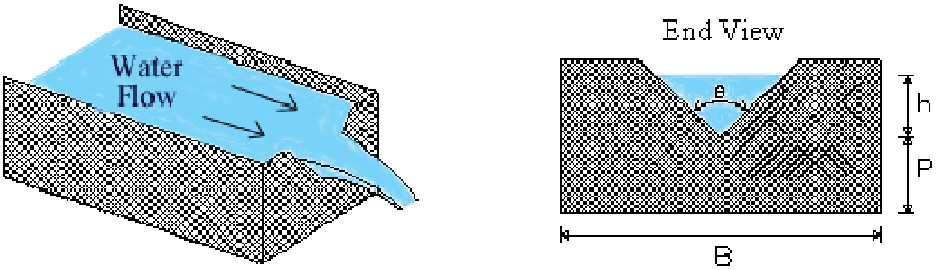


Figure 5.7 V-Notch Weirs
(From: http://web.deu.edu.tr/atiksu/ana52/ani4022.html)

The equation (5.1) is used to determine the discharge flow (NKAYAM, 1999).

$$Q = 8/15\ C_d \sqrt{2g}\ \tan\theta\ h^{5/2} \qquad (5.1)$$

Where:

Q is the discharge (m^3/s)
C_d is the V-notch weir coefficient of discharge
h is the head over the weir (m)
θ is the notch angle (radian)

Typical values of C_d for a triangular weir are between 0.611 and 0.57 depending upon h and Q (Haestad Methods Inc., 2002).

5.4. HYDRAULIC TESTING PROCEDURE

The hydraulic characteristic of the VTA is a very extensive and important part of the testing. This is because the subsequent results will determine significant information such as the treatment capabilities of different VTA prototypes and the associated headlosses with different treatment flows. The tests involved the determination of treatment flows and corresponding headloss with the screen at 0, 22, 33, 44, 55 and 66% blocked condition. The basket's screen was blocked by dense circular foam discs, added one on the top of other. In each test regime, the valve of the system was opened a fraction of a turn each time and all the information relating to the flow rate, inlet and outlet pipe pressure head, inlet and outlet pipe velocity head or dynamic head for Design Treatment Flow (DTF) and Design Peak Flow (DPF) were measured and recorded. DTF is the maximum treatment flow with zero bypass flow, and DPF is the maximum pipeline flow that is designed to be carried (e.g. 13.3 L/s in the case of 100 mm inlet pipe diameter). This was expected to be different in each screen condition; consequently the headloss would be different too.

5.5. DIVERTING WEIR PIT TRAP

The next step of the test which determines the volume flow rate of the stormwater was executed after the first part in which pressure head and velocity head and consequently, the headlosses of SPT were determined. In this part of the experiment, a scale model diverting weir pit with a weir in the middle and 100 mm inlet/outlet pipes for flow/bypass was designed, manufactured and assembled with the previous reservoir, pump and valve via 100 mm PVC pipes, tee junction and manometers similar to the first part of the experiment. The U-shape loop was connected to the exit pipe of the diverting pit at one end and to the other side of the pit separated by the weir, via an adjustable valve in the other end, as shown in schematic Figure 5.8.

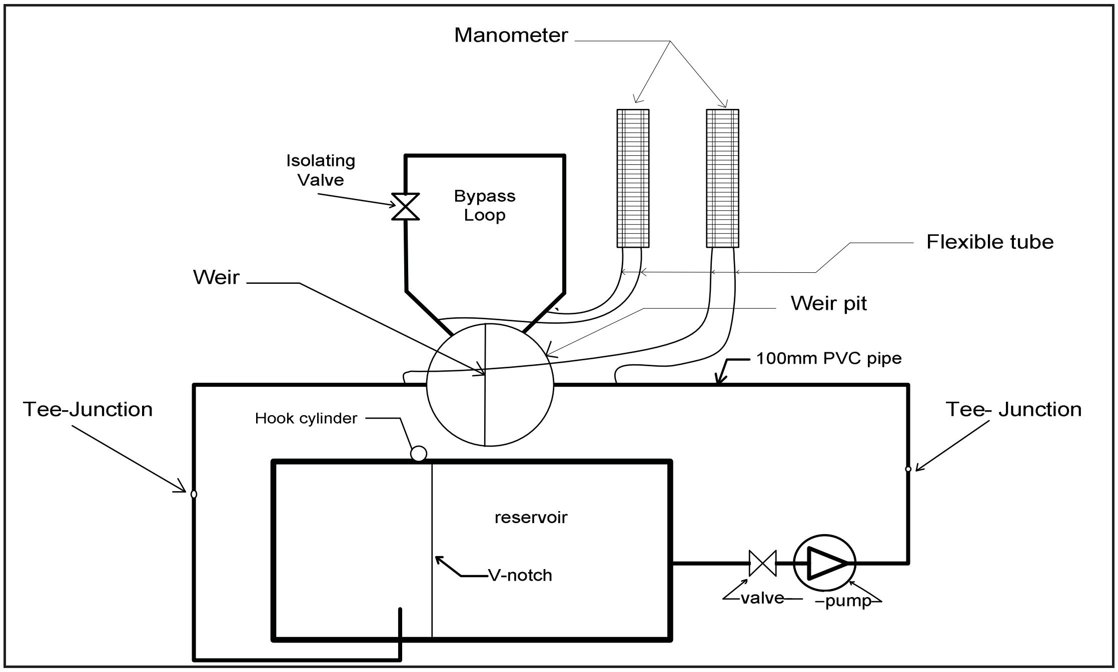


Figure 5.8 Weir Pit and Bypass Loop

The SPT in the first part of the test was basically replaced by a loop of 100 mm piping system and adjustable isolating valve. Two sets of manometers were connected to the inlet and outlets of the main pipe and bypass loop. By starting the pump and adjusting the valve in the main piping system, while the bypass valve is fully open, we regulated the flow through the whole system to get approximately the same flow rate which was passing through the SPT in the first part of the test for each segmental of SPT blockage. This is achieved by reading the height of the water above the V-notch using an externally-installed calibrated hook cylinder to the reservoir and inserting a weir in the diverting weir pit which diverts water through the bypass loop. By adjusting the bypass valve to create the same differential pressure drops across the valve (simulating the SPT's blockage condition), consequently the water level in inlet side of the weir pit increases and here is where the height of the weir plays an important role. By repeating the above process several times and using the experimental equation achieved in first part of the test,

$$h_T = -0.006Q^2 + 10.8\ Q + 6.2 \qquad (5.2)$$

which was achieved in the first part of the experiment, we check the accuracy of the flow versus differential pressure head.

By applying this method we can find the maximum height that each simulated flow (constrained by the differential pressure drop and flow rate, governed by equation 5.2), can be achieved without spilling over the inserted weir. This is basically the maximum flow which can be diverted. Based on this method the new sets of data were collected and the graphs of these sets of data were plotted, which essentially relates weir height to the diverted flow rate. By substituting it in the experimentally-achieved equation, we established another equation relating weir height to flow rate. Basically by completing this stage of the experiment and by applying the scale factor to the existing SPT, one can calculate the capacity of the SPT and required weir height to divert the designated flow to the SPT and detain the debris in the inner basket to avoid the flood and to direct cleaner stormwater to the outlet part of the diversion-weir pit.

Figure 5.9 Experimental Setup of VersaTrap Type A at Curtin University of Technology

CHAPTER 6: EXPERIMENTAL RESULTS

6.1. HYDRAULIC TEST RESULTS

The hydraulic performance of the VersaTrap Type A was determined experimentally in an open environment at the Civil Engineering Department, Curtin University of Technology, Western Australia. In this experiment, the differential velocity head of the inlet and outlet water through the system by incremental increases of the control valve, was measured and flow rate of the system was calculated using the equation:

$$Q = 8/15\ C_d \sqrt{2g}\ \tan\theta\ h^{5/2} \qquad (6.1)$$

In order to avoid any back pressure and turbulence caused by the entrance and exit conditions of the VTA, the manometer connections to the pipe were made at a distance equal to five diameters of the pipe leading to the storm pollutant trap.

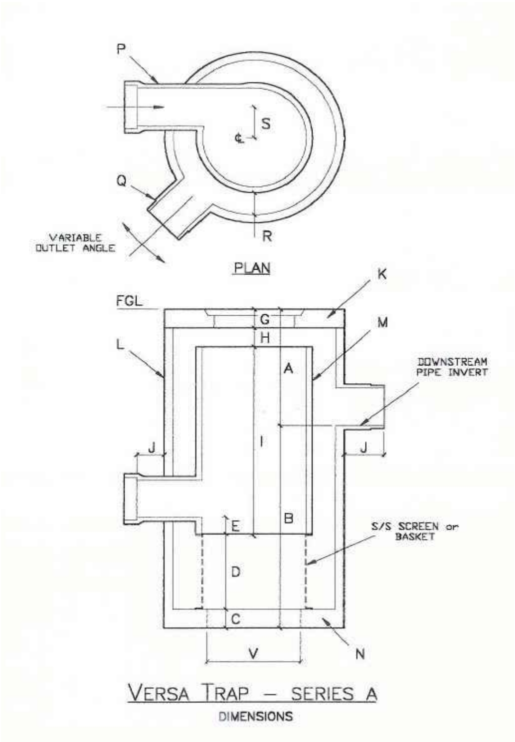


Figure 6.1 Storm Pollutant Trap Series A

Using the Bernoulli or energy equation (6.1), the headloss at each flow rate with each screen blockage was calculated as:

$$V_1^2/2g + P_1/rg + Z_1 = V_2^2/2g + P_2/\rho g + Z_2 + h_L \qquad (6.2)$$

Where:

$V_1^2/2g$ is the velocity head at inlet pipe connection (m)
$P_1/\rho g$ is the pressure head at inlet pipe connection (m)
Z1 is the elevation at inlet pipe connection (m)
$V_2^2/2g$ is the velocity head at outlet pipe connection (m)
$P_2/\rho g$ is the pressure head at outlet pipe connection (m)
Z_1 is the elevation at outlet pipe connection (m)
h_L is the headloss or energy loss between two points (m)

6.2. VersaTrap TYPE A RESULTS

The VTA unit is designed mainly for light commercial and residential area off-line pollutant trapping. The stormwater diverts to the VTA trap by means of a diverting pit trap which is equipped with a rectangular weir. When the stormwater flow is more than the capacity of the VTA, a portion of the stormwater bypasses to the downstream flow by flowing over the weir without entering the treatment chamber during the major events. Hence more comprehensive tests were done in trying to establish the true hydraulic characteristics of the model. At the six different selected screen conditions, illustrating the actual field conditions, all hydraulic characteristics were tested. Design treatment flow (DTF) depends on the screen condition, it decreases as the percentage of blocked screen condition increases. DTF slowly decreases from 7.05 L/s for a zero percentage blocked screen down to 4.48 L/s for a 66% blocked screen. Hence the headloss for each percentage of blockages has different values as depicted in Figure 6.2.

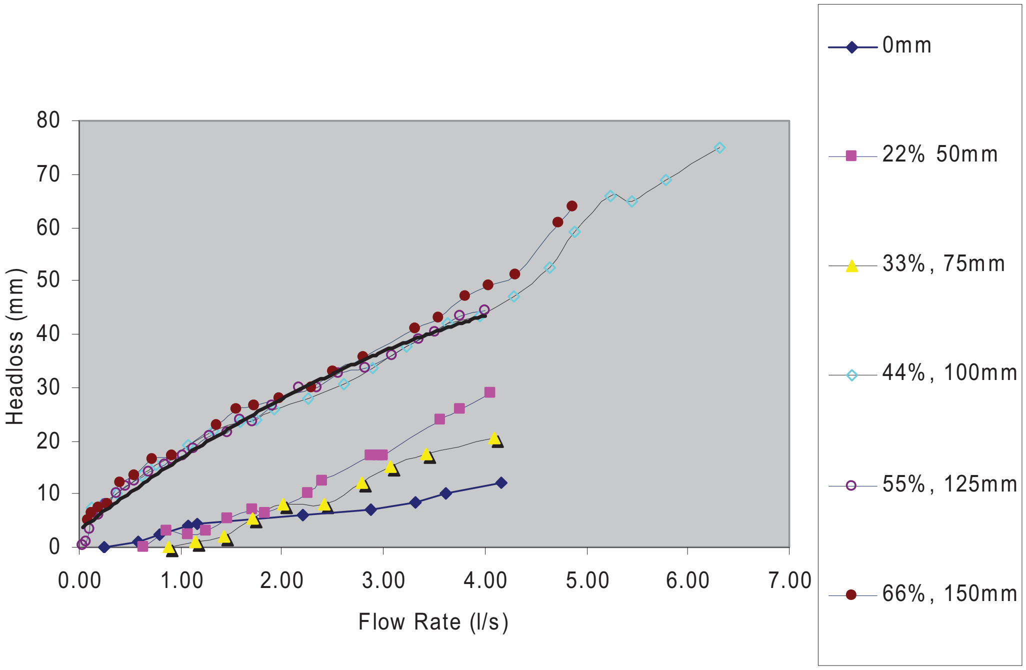


Figure 6.2 Headloss Characteristic Curves for Different Blocked Screen Conditions

The pressure head for the *inlet* pipe for 0 up to 33% blocked screen is greater than 44 to 66% blocked screen due to higher shear stress at low velocities (See Figures 1–3 in Appendix C). As flow and its velocity increases to 44 up to 66%, the logical pattern of the relationship between velocity head and flow follows the general rule of pressure head increase by flow rate increase. The same situation is true with pressure velocity head versus *outlet* flow. Hence the Figure 6.2 represents the differential of inlet and outlet velocity head, versus flow rate. This outcome is similar to study of Allison et al. (1998) and Shin et al. (2005); by increasing the percentage of the blocked screen, the headloss increases. The headloss at 0% blocked screen was raised from 197 to 222 for a 77% blocked screen.

The flow conditions in VersaTraps are often of open channel flow, which is known as *non-pressurised* flow, where the fluid conditions will be considered as gravity flow. Therefore the *Froude number* is very important for determining the velocity, discharge and other factors at all scale model factors. From Table 6-1, seven scale model factors were chosen as real prototype sizes that might be used in the field.

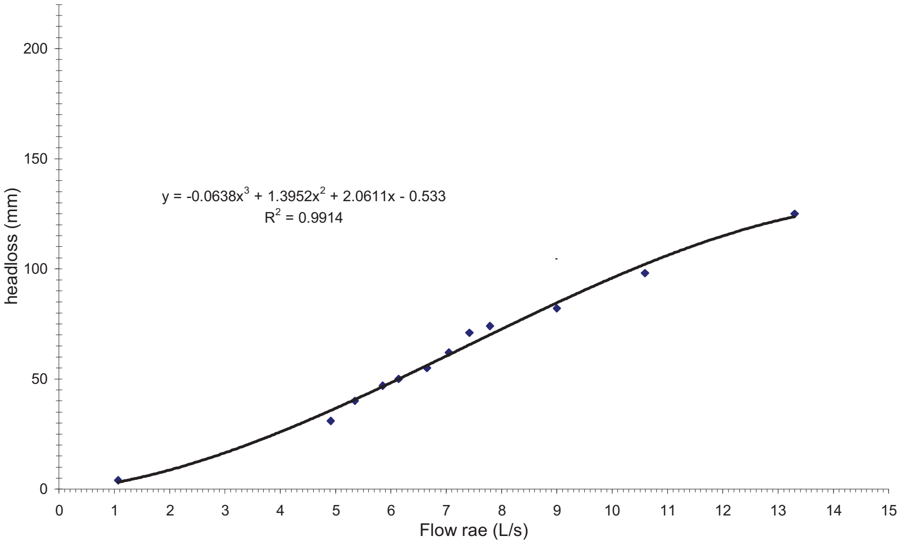


Figure 6.3 Relationship between Headloss and Flow Rate at 0% blocked Screen

In order to find out the headloss values for all selected prototypes, it is necessary to scale the model up to determine the related characteristics of the existing model.

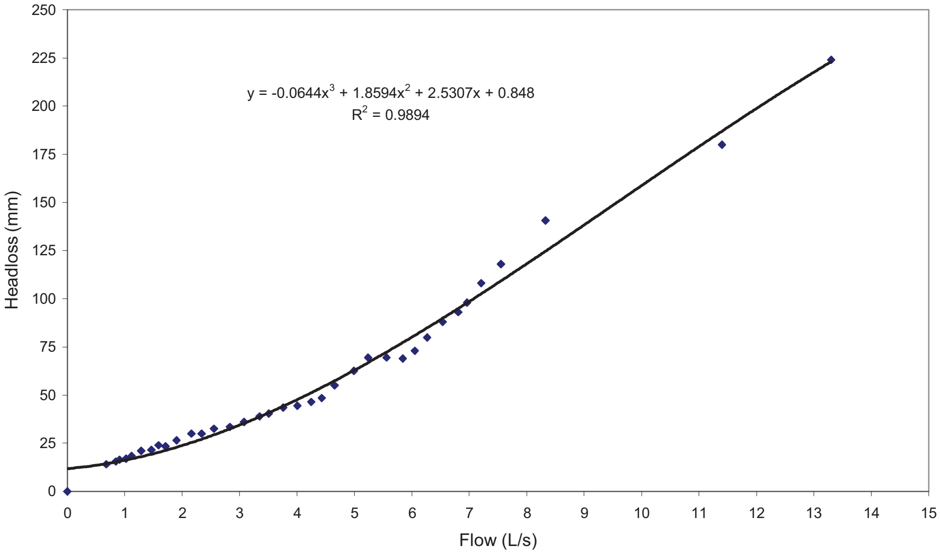
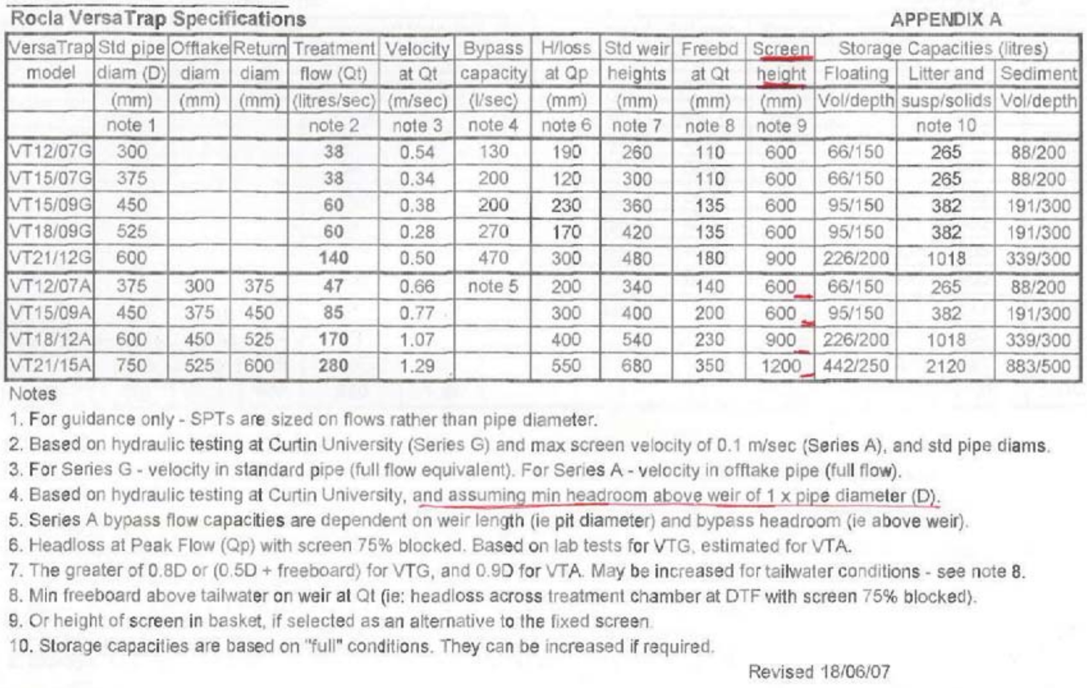


Figure 6.4 Relationship between Headloss and Flow Rate at 55% Blocked Screen

At 55% blocked condition, the flow rate pattern versus headloss is sharper than a 0% blocked screen. This means more differential pressure headloss because more energy is required to push the flow through the screen at this stage. Therefore we observe higher headloss due to higher screen blocked conditions.

Table 6.1 VersaTrap Size Specification



Rocla VersaTrap Specifications

APPENDIX A

VersaTrap	Std pipe	Offtake	Return	Treatment	Velocity	Bypass	H/loss	Std weir	Freebd	Screen	Storage Capacities (litres)		
model	diam (D)	diam	diam	flow (Qt)	at Qt	capacity	at Qp	heights	at Qt	height	Floating	Litter and	Sediment
	(mm)	(mm)	(mm)	(litres/sec)	(m/sec)	(l/sec)	(mm)	(mm)	(mm)	(mm)	Vol/depth	susp/solids	Vol/depth
	note 1			note 2	note 3	note 4	note 6	note 7	note 8	note 9		note 10	
VT12/07G	300			38	0.54	130	190	260	110	600	66/150	265	88/200
VT15/07G	375			38	0.34	200	120	300	110	600	66/150	265	88/200
VT15/09G	450			60	0.38	200	230	360	135	600	95/150	382	191/300
VT18/09G	525			60	0.28	270	170	420	135	600	95/150	382	191/300
VT21/12G	600			140	0.50	470	300	480	180	900	226/200	1018	339/300
VT12/07A	375	300	375	47	0.66	note 5	200	340	140	600	66/150	265	88/200
VT15/09A	450	375	450	85	0.77		300	400	200	600	95/150	382	191/300
VT18/12A	600	450	525	170	1.07		400	540	230	900	226/200	1018	339/300
VT21/15A	750	525	600	280	1.29		550	680	350	1200	442/250	2120	883/500

Notes

1. For guidance only - SPTs are sized on flows rather than pipe diameter.
2. Based on hydraulic testing at Curtin University (Series G) and max screen velocity of 0.1 m/sec (Series A), and std pipe diams.
3. For Series G - velocity in standard pipe (full flow equivalent). For Series A - velocity in offtake pipe (full flow).
4. Based on hydraulic testing at Curtin University, and assuming min headroom above weir of 1 x pipe diameter (D).
5. Series A bypass flow capacities are dependent on weir length (ie pit diameter) and bypass headroom (ie above weir).
6. Headloss at Peak Flow (Qp) with screen 75% blocked. Based on lab tests for VTG, estimated for VTA.
7. The greater of 0.8D or (0.5D + freeboard) for VTG, and 0.9D for VTA. May be increased for tailwater conditions - see note 8.
8. Min freeboard above tailwater on weir at Qt (ie: headloss across treatment chamber at DTF with screen 75% blocked).
9. Or height of screen in basket, if selected as an alternative to the fixed screen.
10. Storage capacities are based on "full" conditions. They can be increased if required.

Revised 18/06/07

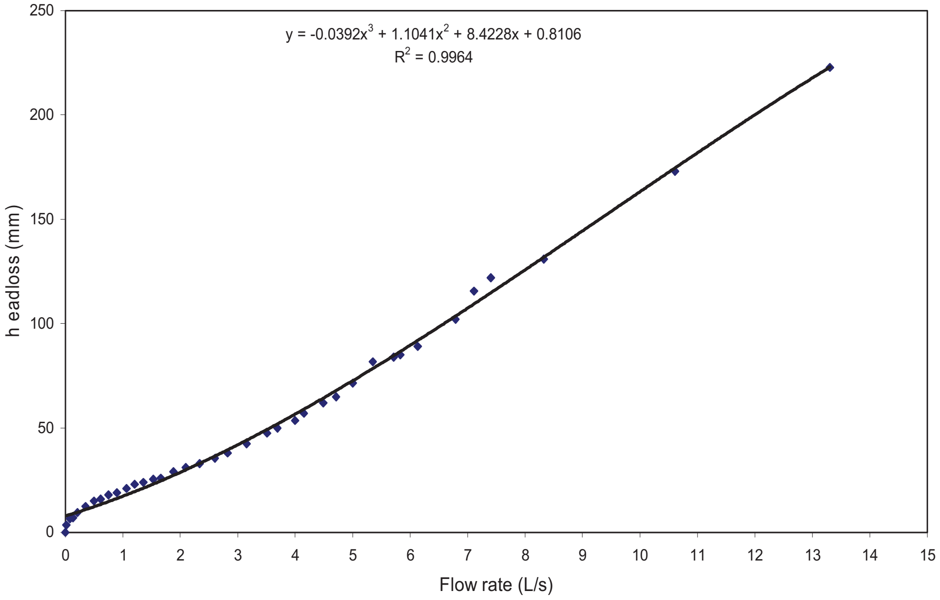


Figure 6.5 Relationship between Headloss and Flow Rate at 77% Blocked Screen

In a 77% blocked condition (which is considered the critical flow condition), the flow rate pattern versus headloss is sharper than a 0% blocked screen condition, which is the lowest limit critical condition. As can be observed from Figure 6.5, this means sharper slope differential pressure headloss than zero and other less screen blocked conditions. The headloss pressure is also higher than the previous (55% blocked) condition.

So for the upper critical condition; considering a 50–55% blocked screen cleaning limit for the trap, according to manufacturer's recommendation, 77% indicates that pollutant quality is already trapped by the SPT and also to be conservative. Following the same method of scaling, Tables 6-2 and 6-3 illustrate all hydraulic characteristics between 0 and 77% blocked screen conditions scaled up to different sizes of a real existing prototype.

From the laboratory experiments, the VersaTrap Type A design treatment flow rates range is approximately 30 L/s for prototype VT 10/06A and up to 300 L/s for VT

12/15A. Also, the capacities of the smallest and largest size of this SPT can approximately handle from 75 L/s up to 750 L/s at design peak flow.

Therefore, the headloss of prototypes ranges from 352 mm to 880 mm respectively from the smallest to the largest SPT Type A. These results indicate a satisfactory outcome for the hydraulic performance of the model, because in other studies which were conducted by CDS Technologies, the typical maximum headloss of the unit was about 400 mm at 550 L/s (Allison et al., 1998).

At the 77% blocked screen condition, the hydraulic performance of the VTA was tested at the end. It should be noted that the treatment flow at this condition is very close to a full blocked screen condition, so design treatment flow is less important than zero percent blocked condition.

Table 6-2 Hydraulic Test Results for the VTA (0% Blocked Screen Condition at 13.3 L/s)

	Model	**VT 10/06**	**VT 12/07**	**VT 15/09**	**VT 18/10**	**VT 18/12**	**VT 21/13**	**VT 21/15**
Scale Factor	1	2	2.5	3	3.5	4	4.5	5
DTF (L/s)	5.35	30.26	52.8	93.4	122.60	171.2	229.8	299.0
DPF(L/s)	13.3	75.2	131.4	207.3	304.8	425.6	571.3	743.5
h_L (mm)@ DPF	125	250	312.5	375	437.5	500	562.5	625
Hi (mm)	641	1282	1602.5	1923	2243.5	2564	2884.5	3205
Ho(mm)	602	1204	1505	1806	2107	2408	2709	3010
ΔH (mm)	39	78	97.5	117	136.5	156	175.5	195
Pipe diameter (mm)	100	225	300	300	375	450	525	600
Velocity in pipe (m/s)	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63
K_e	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45

Table 6-3 Hydraulic Test Results for the VTA (77% Blocked Screen Condition at 13.3 L/s)

	Model	**VT 10/06**	**VT 12/07**	**VT 15/09**	**VT 18/10**	**VT 18/12**	**VT 21/13**	**VT 21/15**
Scale Factor	1	2	2.5	3	3.5	4	4.5	5
DTF (L/s)	4.49	25.4	44.37	70.0	103.0	143.7	193.0	251.0
DPF(L/s)	13.3	75.2	131.4	207.3	304.8	425.6	571.3	743.5
h_L (mm)@ DPF	222.7	445.4	556.75	668.1	779.45	890.8	1002.15	1113.5
Hi (mm)	845.1	1708.2	2112.7	2535.3	2957.8	3380.4	3802.9	4270.5
Ho(mm)	702.2	1204	1044.2	1806	2107	2408	2709	3010
ΔH (mm)	142.9	504.2	1068.5	729.3	850.8	972.4	1093.9	1260.5
Pipe diameter (mm)	100	225	300	300	375	450	525	600
Velocity in pipe (m/s)	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.63
K_e	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65

6.3. THE HEADLOSS COEFFICIENT

The headloss coefficient (K_e) for gross pollutant manufacturers is used to show the hydraulic performance of their products. So it was decided to calculate the Ke in every blocked screen condition in this series of experiments. As mentioned before, the flow of the stormwater in the VersaTrap pollutant trap is considered as open channel flow (non-pressurised flow). In the previous section, headloss calibrations under open channel flow and full pipe flow conditions have been conducted to derive the headloss coefficient for the full range of flow conditions encountered by the VesaTrap unit. The headloss coefficient value was determined as the ratio of the energy loss to the equivalent full pipe velocity head ($V^2/2g$) at the inlet pipe. The lower the headloss coefficient, makes the system more suitable in a wider range of urban locations including low-lying areas.

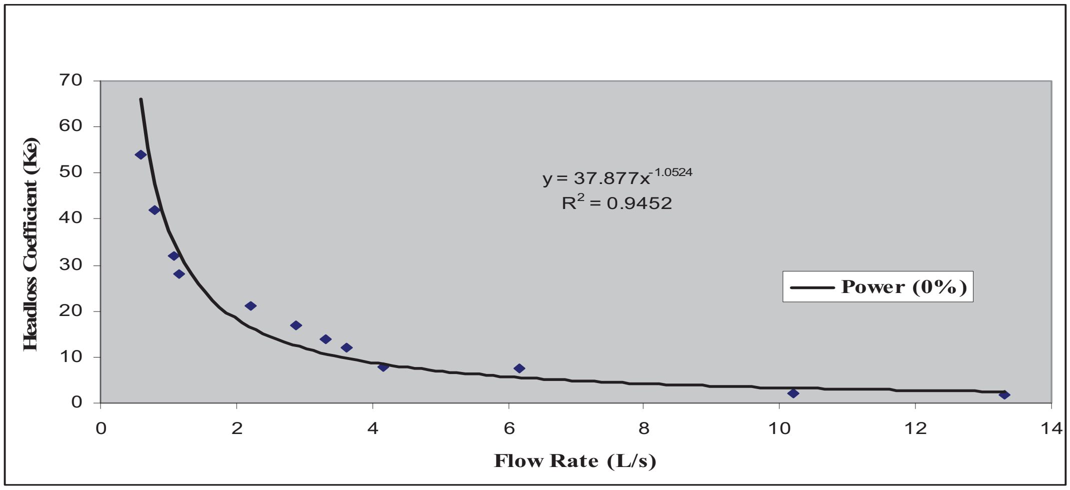


Figure 6.6 Headloss Coefficient and Flow Rate at 0% Blocked Screen VersaTrap Type A

The value of the headloss coefficient increases with flow rate increase. In 0% condition, the value of the headloss coefficient increases and approaches the value of 1.6 at DPF condition as appears in Figure 6.6. This is a reasonable value when compared with other GPTs used around Australia. For the continued deflection separation (CDS) unit, the headloss coefficient value was around 1.3 (Wong, 1997). The headloss coefficient values of the first four screen blocked conditions ranged from 1.6 for 0% up to 2.5 for a 75% blocked condition (Figure 6.7).

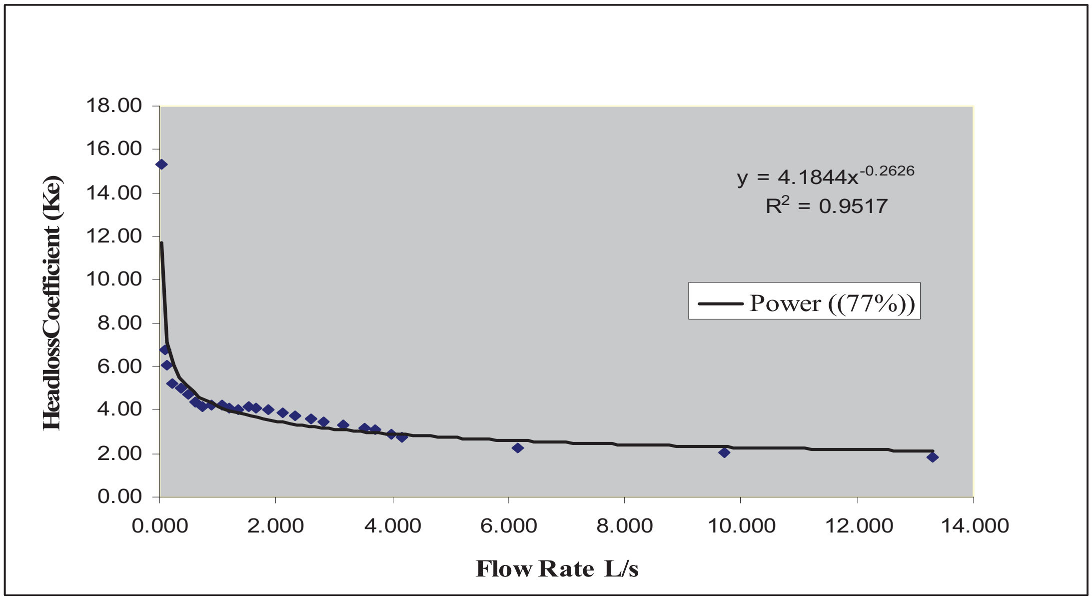


Figure 6.7 Headloss Coefficient and Flow Rate at 77% Blocked Screen VersaTrap Type A

Thus by taking the average of the results from 0% up to a 77% blocked screen condition, it should be noted that the value of the headloss coefficient at DPF is around 1.78 (Figure6.8). This is thought to be very acceptable and an appropriate value to use in investigating the overall effect of the VersaTrap unit on flow rate capacity of the system.

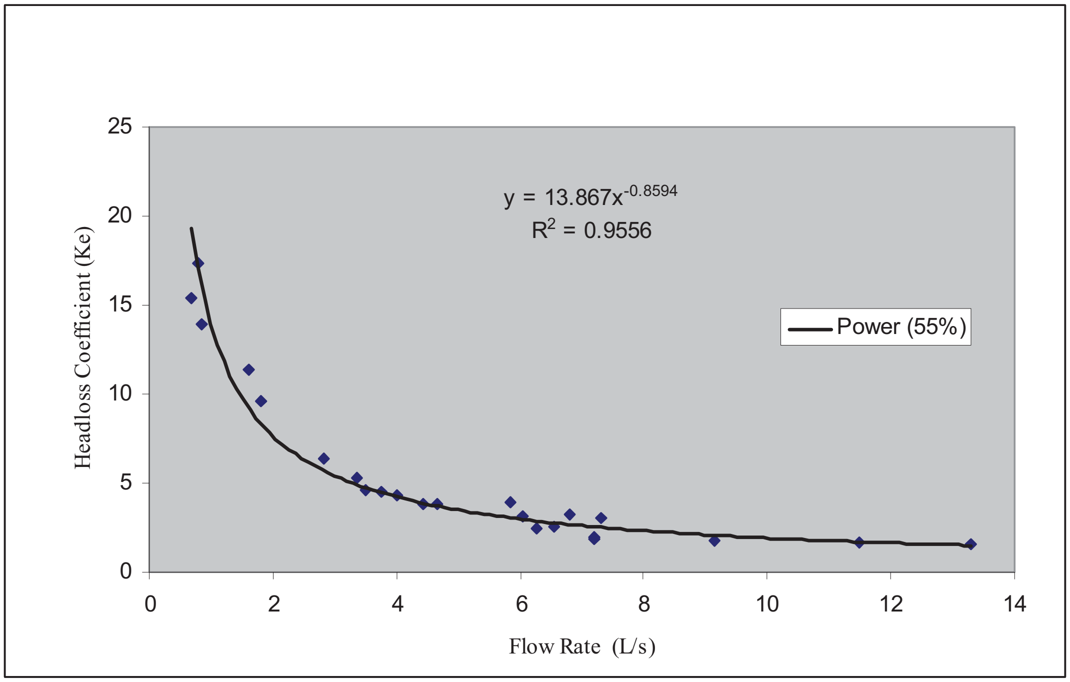


Figure 6.8 Headloss Coefficient and Flow Rate at 55% Blocked Screen VersaTrap Type A

6.4. WEIR HEIGHT AND INLET PIPE DISCHARGE DIAMETER

As it can be observed in Figure 6.9, the pressure drop of the flow—up to the weir height of 100 mm (first four segments of the curve)—decreases due to the fact that creating a half-pipe saddle (equal to 50 mm in height) for the water transition in the weir pit, creates a smooth bed for water flow transition. The y and x presented in the equation of Figure 6.9 represent pressure drop and flow rate.

For flow in the pipe with a weir height of less than 100 mm and guided flow through a half saddle pipe, according to the experimental results, the pressure drop decreases with flow. When weir height exceeds 100 mm (refer to Figure 6.10), the water flow and pressure drop achieve a regular pattern and by increasing flow, pressure drop increases. The average R^2 value of the first four results is 0.987. (Knowing the fact that maximum water flow occurs at slightly less than full depth.)

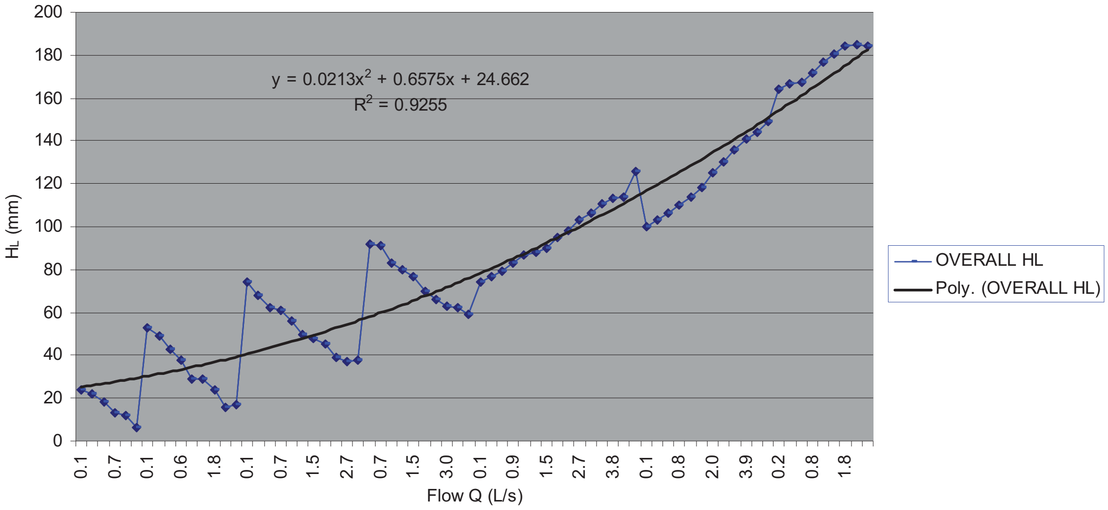


Figure 6.9 Flow vs. Weir Headloss

For the maximum flow or rate of discharge, the Manning formula indicates that $AR_h^{2/3}$ must be a maximum. Substituting the preceding expression for A and R_h into $AR_h^{2/3}$ and differentiating with respect to θ, setting equal to zero and solving for θ gives θ = 151.2°, which corresponds to y = 0.938D for the condition of maximum discharge.

For weir heights of greater than pipe diameter, the headloss of the flow up to 2D from Figure 6.9 was separated and graphed separately; with consequent polynomial equation and coefficient of determination (R^2 = 0.956) presented in Figure 6.10. The headloss from first part of the test is:

$$H_L = 0.056\,Q^2 + 1.1\,Q + 79 \qquad (6.3)$$

Equation 6.3 can be used for finding the optimal weir height in respect to inlet pipe diameter of the diverting storm pollutant used for an off-line Rocla Gross Pollutant Trap model of VersaTrap Type A. Equation 6.3 relates the expected headloss due to the flow rate of up to 23.6 l/s for the scale model.

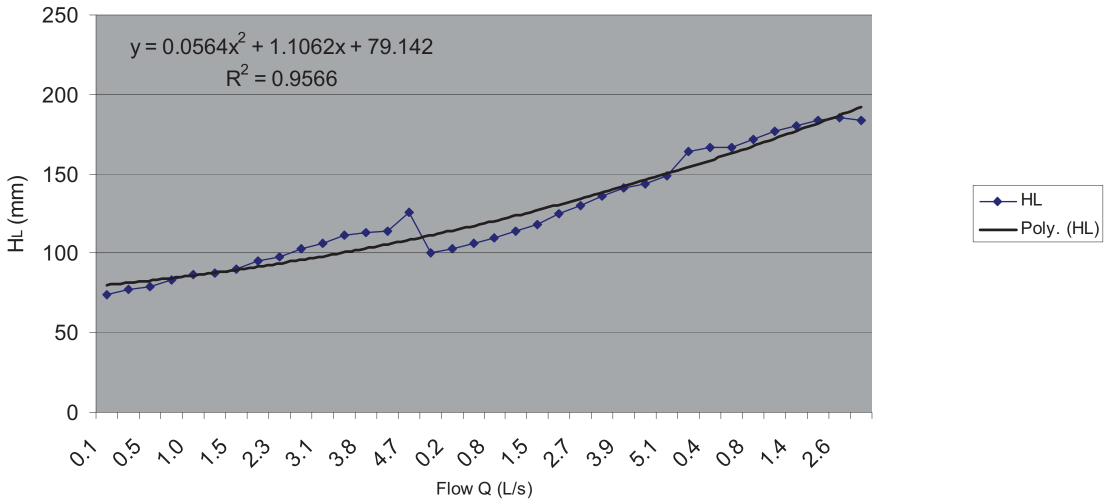


Figure 6.10 Flow vs. Weir Headloss (Weir > D)

By considering the second degree polynomial equation as shown on Figure 6.11, where y and x are height of flow over weir (W_{OF}) and flow rate:

$$W_{OF} = -0.276Q^2 + 13.05Q + 9.1 \quad (6.4)$$

By differentiating it in respect to Q and equating it to zero we find the maximum flow,

$Q_{Max} = 23.6$ l/s.

By substituting this value in above 10, we get the maximum height of flow over the weir, $W_{OF} = 163$ mm. This means that the optimum flow over the weir occurs when the ratio of the weir to diameter of the pipe is 1.63, or in other words,

$$W_{OF} = 1.63D. \quad (6.5)$$

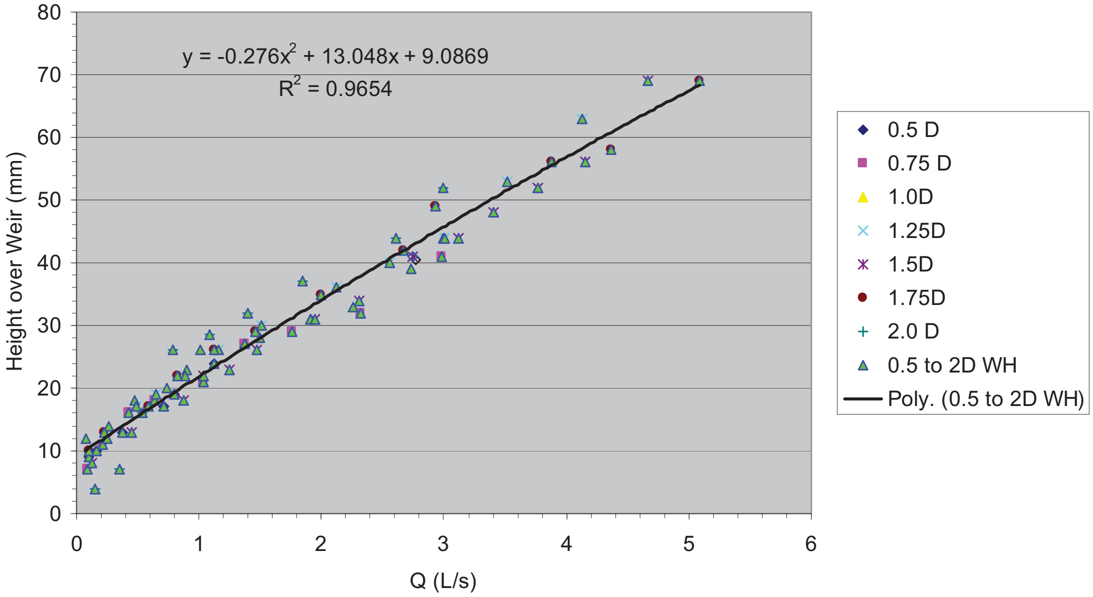


Figure 6.11 Flow Vs. Overflow from Weir

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS

This test conducted by this research primarily focused on the performance of the Rocla Versa Trap (gross pollutant trap) Type A by testing the hydraulic performance (including the relationship between headloss and flow rates for different basket blockages imposed) and the relationship between pipe diameter and flow rates and pressure loss of the Versa Pollutant Trap. A rigorous experimental study was conducted to determine the performance of the model. The hydraulic tests conducted and the results indicated that the headloss proportionally increased as the flow rate increased in each configuration. The headloss increases whenever the blocked screen percentage increases. Consequently, the pollutant removal of the VTA was inversely proportional with the increase of basket blockage.

7.1.1. HYDRAULIC TEST RESULTS (PRESSURE DROP)

At tested different blocked screen conditions, as the discharge increases, headloss increases. It was also found that as the blockage increases, the headloss increases. Up to a 77% blocked condition, the headloss had an acceptable value of 222.7 mm. The headloss was the lowest at 0% and the highest of approximately 1113 mm at a 77% blocked condition. When the basket was 55% blocked, the headloss coefficient was determined at a value of 1.52. This value is very close to the experimental research done on CDS by Allison, 1999.

7.1.2. SCALE MODEL RESULTS

For finding the hydraulic characteristics of a VersaTrap Type A, the concluded results for this specific model was scaled-up by proper scaling methods to six different real-sized prototypes. The lowest headloss when the basket is clean and no blockage is applied to the basket is found to be 250 mm. Because the VTA is designed for stormwater treatment, the device can handle about 743 L/s at the largest-scaled size prototype (VT21/15A). Therefore the headloss could be up to 1113 mm. The results indicate a satisfactory outcome for the hydraulic performance of the VersaTrap Type A compared to other stormwater devices such as the CDS unit. Thus for VTA models the diverting pit weir height it is found to be proportional to the pipe diameter and flow rate; and optimum weir height is 1.3 times the inlet pipe diameter.

7.1.3. OVERALL CONCLUSION

The conducted experiments on VersaTrap Type A clarified that the VersaTrap Type A is a very efficient gross pollutant trap. Laboratory tests and concluded results also showed the importance of regular maintenance for the VersaTrap to perform at its best efficiency. This was demonstrated by the height fluctuations of the headloss when the trap becomes highly blocked. The experiments also acquiesced with the assumption that this type of VersaTrap is designed to capture the coarser fractions of sediments by the construction of associated wetlands or bio-retention zones—to achieve higher removal of the pollutants associated with the finer sediments such as nutrients and heavy metals—is highly recommended. Furthermore, this experiment concludes that VersaTraps are not only very efficient in the trapping of gross pollutants in commercial and residential areas, but also are partially capable of removing chemical contaminated particles larger than 5 mm in diameter. This experiment also concluded that optimum weir heights in diversion pits can be achieved by considering the proportionality of inlet pipe diameter to weir height. It should be pointed out that this low head loss will help in self cleaning of VersaTrap.

7.2. RECOMMENDATIONS

Although there has been much development in trapping pollutants from waste/stormwater, Australia is characterised by a very uneven distribution of its human population; where two thirds of its population live in the capital cities and 90% live within 120 km of the coast, with a consequent impact on water demand and water pollution.

Much research has been conducted on updating and improving the water quality of runoff and stormwater. However the majority of this research has been concentrated on extracting only one type of pollutant from stormwater. The outcome is usually leads to:

i) Increasing the pipe diameter of the inlet and outlet of traps.
ii) Changing the size of the blocking basket.

So it is recommended that further study should conducted in order to consider:

- The effects of chemicals such as nutrients and sediments in the filtration process
- Updating measuring devices such as electronic flow meters and manometers to provide better measuring and collecting of data for value of coefficients in inlet/exit pipes
- Development of VersaTrap models to conduct multi-purpose functioning such as collecting oil spill and other chemicals such as nutrient heavy metals and sediments
- Improvement of the VTA by further reduction in energy consumption of the device by improving the construction of the device

7.2.1. GUIDELINES TO BE CONSIDERED IN THE PLANNING AND DESIGN OF NEW AND DEVELOPMENT PROJECTS

1. Minimise the amount of impervious surfaces and directly connected impervious surfaces in areas of new development and redevelopment.

2. Use on-site infiltration of runoff in areas with appropriate soils where the infiltration of stormwater would not pose a potential threat to groundwater quality.

3. Implement pollution prevention methods supplemented by pollutant source controls and/or treatment controls. Where practical, use strategies that control the sources of pollutants or constituents (i.e. the point where water initially meets the ground) to minimise the transport of stormwater and pollutants offsite.

4. Preserve and, where possible, create or restore areas that provide important water quality benefits, such as riparian corridors, wetlands and buffer zones.

5. Limit disturbances of natural bodies and natural drainage systems caused by development, including roads, highways and bridges.

6. Use existing drainage master plans or studies to estimate increases in pollutant loads and flows resulting from projected future development and require incorporation of structural and non-structural BMPs to mitigate the projected increases in pollutant loads in runoff.

7. Identify and avoid development in areas that are particularly susceptible to erosion and sediment loss, or establish development guidance that protects areas from erosion and sediment loss.

8. Eliminating illicit discharge in the design phase.

9. Control the post-development peak stormwater runoff discharge rates and velocities to prevent or reduce downstream erosion, and to protect stream habitat.

10. Initiate public education programmes to remind people, in both residential and commercial situations, where pollutants end up.

CHAPTER 8: REFERENCES

8.1 REFERENCES

Akers, R.J. and Ward, A.S., 1977. “Filtration Principles and practice” , chapter.2, Vol.1, C. Orr, (ed.) Dekker, New York.

Allison, R. A., Chiew, F. H. S., and McMahon, T. A. (1998a). *A decision-support-system for determining effective trapping strategies for gross pollutants.* Technical Report 98/3, Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.

Allison, R. A., Walker, T., Chiew, F. H. S., O'Neill, I. C., and McMahon, T. A. (1998b). *From roads to rivers; gross pollutant removal from urban waterways.* Technical Report 98/6, Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.

Allison, R.A., and Pezzaniti, D. (2003). *Gross pollutant and sediment traps.* In T. H. F. Wong (Ed.), Australian Runoff Quality. Sydney, Australia: Institution of Engineers, Australia.

Allison, B., Wong, R.A., T H F., McMahon T. A. 1998. “The CDS Stormwater Pollution Trap: Field Trials”

Allison, R., 1997. “Effective Gross Pollutant Removal from Urban Waterways”, PhD Thesis, University of Melbourne.

Allison K A and Chiew F H S, 1995. “1Year Monitoring of Stormwater Pollution for various Land Uses in an Urban Catchment”. Proc. 2nd Inc. Sym. on Urban Stormwater Management, Melbourne Australia, 11-13 July, IE Australia, NCP 95/03, Vol.2, pp 511-516

Allison, R. Chiew, F. & McMahon, T. 1997. “Stormwater Gross Pollutants” “Industry Report”. ISBN 1 876006 27 7. Australia. 97/11.

Allison, R. Chiew, F. & McMahon, T. 1997. “Stormwater Gross Pollutants” “Industry Report”. ISBN 1 876006 27 7. Dec 1997.

Allison, R. and Pezzaniti, D., 2003. “Gross Pollutant and sediment traps”. T.H.F. Wong (Editor), Australian Runoff Quality. Institution of Engineers, Australia, Sydney, Australia.

Allison R.A., Chiew F.H.S. and McMahon, T.A. 1997a. “Stormwater Gross Pollutants”, Industry Report 97/11, Cooperative Research Centre for Catchment Hydrology, December 1997.

Allison R.A., Chiew F.H.S. 1995. “Monitoring of Stormwater Pollution for Various Land-uses in an Urban Catchment”. Proc. 2nd Int. Sym. On Urban Stormwater Management, Melbourne Australia, 11-13 July, IE Aust., NCP 95/03, Vol.2, pp 511-516.

Alter, W.1995. “The Changing Emphasis Municipal Sweeping May be Tanderm”., American Sweeper, Volume 4, number 1, pp.6.

Ancia, P., Frenay, J., and Dandois, P., 1997, “comparison of Knelson and Falcon Centrifugal Separators” In Innovation in Physical Separation Technologies, Falmouth, UK: IMM, pp.53-62.

Andoh, R. 2006. “CFD Saves $50,000 in Design of Stormwater Separator”. Hydro International, Portland, Maine, USA. Fluent News Summer 2006.

Andrew L. Simon, Scott F. Korom. 1996. “Hydraulics”. (Fourth Edition). August 5, 1996, Appendix D. “Stormwater Quality Controls in SLAMM”.

Appendix 4-8, 1996. Best Management Practices and nutrient Loading Standards” (from Nitrogen Concentrations in Well Water: A Handbook for Protecting Community Resources, Pioneer Valley Planning Commission, June, 1996).

Argue J. and Pezzaniti, D. 1996.”Evaluation of RSF100 Gross Pollutant Trap” –Stage 2 Final Report, Urban Water Centre, University of South Australia.

Armitage N. P., et al., 1998. “The Removal of Urban Litter from Stormwater Conduits and Streams”, WRC Report No. TT95/98 Water Research Commission, South Africa.

Ashraf Saadat, 2003 “Pollutant build up and wash off modelling on impervious surfaces” PhD Thesis, Curtin University of Technology.

ASCG INCOPORATED, 2005,”AMAFCA/ALBQUE MS4, FLOATABLE AND GROSS POLLUTANT STUDY” Sep. 2005.

ASCG INCOPORATED, 2005. “FLOATABLE AND GROSS POLLUTANT STUDY” AMAFCA/ALBUQUERQUEMS4, OCTOBER 2005.

ASCE, 2000. “National Stormwater Best Management Practices (BMP) Database” American Society of Civil Engineers/US Environmental Protection Agency (200).Available from www.Asce.org/peta/tech/nsbd01.html.

Australian Government National Water Reform Task Force. “CSIRO Land and Water: Canberra”. ISBN 0 643 060502.

Baker, R.A.1980. “Contaminants and Sediment”, Ann Arbour Science, Butterworth Group, Michigan.

Ball, J.E. 2002. “STORMWATER QUALITY AT GENTENNIAL PARK”, SYDNEY, AUSTRALIA Research Report No.205 June.

Bannerrnan, R., Baun, K. and Bohn, vf. 1983. “Evaluation of Urban Non-Point Source Pollution Management in Milwaukee country Wisconsin”. Vol 1.

Barrett, M.E., 1999. “Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices”, Texas Natural Resource Conservation Commission Report RG-348, June, (1999).

Bateman, M. Livingston, E. H., and Cox, J. N D. “Overview of Urban Retrofit Opportunities in Florida” Stormwater Management Program Florida Department of Environmental Protection Tallahassee, Florida.

Bautista, M. F. and Geiger, N. S. 1993. “Wetlands for Stormwater Treatment Water Environmental and Technology 5(7): pp 50-55

Beniuk, V.G., Vadeikis, C.A. & Enraght-Moody, J.N., 1994. “Centrifugal Jigging of Gravity Concentrate and Tailing at Renison Limited”. Minerals Eng., 7 (5/6), 577-589.

Bergstr, Om, J. Vomhoff, H. 2004. “Velocity measurements in a cylindrical hydro cyclone operated with an opaque fibber suspension”. Minerals Engineering 17 (5), 599-604.

Bergstr, Om, J. Vomhoff, H. 2006. “Experimental hydro cyclone flow field studies”. Separation and Purification Technology 53 (2007) 8-20.29th Sep.

Between Sediments and Water, Banff, Canada 2002.

Bergstr, Om, J. 2004. “Fibber Suspension Velocity Measurements in Cylindrical Through-Flow Hydro cyclone”. Licentiate Thesis, Royal Institute of Technology, Department of Fibre and Polymer Technology. Stockholm, Sweden.

Blau, H. (1970). “Die Berechnung flachkroniger Einlaufe von Schachtuberfallen”, Wasserwirthchaft-Wassertechnik, No.6, pp.209-212.

Boisson, N., Malin, M.R., 1996. “Numerical prediction of two-phase flow in bubble columns”. International Journal for Numeric Methods in Fluids 23, 1289-1310.

Boysan, F., Ayers, W.H. & Swithenbank, J. 1982. “A fundamental mathematical modelling approach to cyclone design”. Transcripts of the Institute of Chemical Engineers 60, 222-230.

Borchers, O., Busch, C., Sokolinchin, A., Eigenberger, G., 1999. “Applicability of the stand k-e turbulence model to the dynamic simulation of bubble, part II: comparison of detailed experiments and flow simulations”. Chemical Engineering Sciences 54, 5927-5935.

Bradley D., 1965. “The Hydro cyclone”, Pergamum, Oxford.

Brennan, S.N. 2002. "On and Control: The Use of Dimensional Analysis in Controller Design". PhD Thesis. University of Illinois at Urbana- Champaign.

Brueske, C. C. 2000. "Technology Review: Ultra- Urban Stormwater Treatment Technologies", Department of Civil and Environmental Engineering University of Washington Seattle, WA September 1, 2000.

Burt, R.O. assisted by Mills, C., 1984. "Gravity Concentration Technology, Amsterdam". Elsevier Science Publishers BV, 607.

Burt, R.O., Korinek, G., Young, S.R., and Deveau, C. 1995. "ULTRAFINE TANTALUM RECOVERY STRATEGIES" Minerals Engineering, Vol 8, pp. 859-870. 4th April.

Burt, R. O., 1997, "Gravity concentration- still a 'Modern' process In Innovation in Physical Separation Technologies", Falmouth, UK: IMM, pp. 147-158.

Burt, R.O., 1992. "Gravity Concentration of Ultra fines- a Literature Review of Centrifugal Concentrating Devices". MDA Report, 22 (October 1992).

California Storm Water Best Management Practise Handbook: Municipal. 1993 March

California Stormwater BMP Handbook, 2003. "New Development and Redevelopment", January 2003 www.cabmphandbooks.com

Calvert. J.B. 2003. "The Vortex". (http://www.du.edu/~jcalvert/tech/fluids/vortex.htm)

CASQA 2003. "Vortex Separator". California Stormwater BMP Handbook. www.cabmphandbook.com.

Centre for Streamside Studies, 1991, "College of Forestry and College of Ocean and Fishery Sciences", University of Washington Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska, EPA/910/9-91-001

Chan, B.S.K., Mozley, R.H. & Childs, G.J.C. 1989. "The Multi-Gravity Separator (MGS)- a Mine Scale Machine". 107-123 in Dowd, P.A. (ed.) Miner. Process. in the United Kingdom London: IMM.

Chan, B.S.K., Mozley, R.H., and Childs, G.C.J., 1989, "The multi-gravity separator (MGS)- a mine scale machine" In Mineral Process in the United Kingdom, London: IMM, pp. 107-123.

Chan, B.S.K., Mozley, R.H., and Childs, G.J.C.,1991, "Extended trials with the high tonnage Multi- Gravity Separator", Miner. Eng., 4 (3=4), pp. 489-496.

CITY OF PORTAGE DRAINAGE AND STORMWATER MANAGEMENT- BEST MANAGEMENT PRACTICE MANUAL

Curtis, M.C. 2002. "STREET SWEEPING FOR POLLUTANT REMOVAL", Watershed Management Division February, 2002.

Coburn, J., 1994. "Cleaning Up Urban Stormwater: The Storm Drain Stencilling Approach", Journal of Soil and Water Conservation, Vol. 49, No. 4, p.312.

Control Through Non-structural Measures, Prepared for the Department of Conservation and Recreation, Division of Soil and Water Conservation, Virginia. Cited at www.nonaregion.org/es_pubs.htm#bmp

Cordingley, M.G., 1997, "MGS developments and strategies in fine gravity separation techniques" In Innovation in Physical Separation Technologies, Falmouth, UK: IMM, pp. 75-82.

Chang, F. & Dhir, V.K. 1994. "Turbulent flow field in tangentially injected swirl flows in tubes". International Journal of Heat and Fluid Flow 15 (5), 346-356.

CHANGIRWA, R. ROCKWELL, M.C. FRIMPONG, S. and SZYMANSKI, J. 1999. "HYBRID SIMULATION FOR OIL-SOILIDS-WATER SEPERATION IN OIL SANDS PRODUCTION". 0892-6875(99)00134-X. School of Mining and Petrolueum Eng., University of Alberta, Edmonton, AB,T6G 2G7 Canada 27th August 1999).

Chrispijn, J.A. 2003. "Stormwater Pollution in Sullivans Cove: An Unwanted By-product of Development" Habort City Council.

Chrispijn, J., 2004. "Assessing Different At-sources Stormwater Treatment Devices in Hobart:- Sullivans Cove and Brooker Highway Performance Trails", Hobart City Council.

Clay, H.2001. "Stormwater Management Plan DRAFT", Water and Sewerage, Wentworth Shire Council, April 2001

Chan, B.S.K., Mozley, R.H. & Childs, G.J.C., 1989. "The Multi-Gravity Separator (MGS)- a Mine Scale Machine", 107-123 in Dowd, P.A. (ed.) Miner. Process. in the United Kingdom London: IMM.

Chan, B.S.K., Mozley, R.H. & Childs, G.J.C.,1989, "The Multi-gravity separator (MGS)- a mine scale machine" In Mineral Process in the United Kingdom, London: IMM, pp.107-123.

Chester Bounty Conservation District, 2002. "SITE 20, Chester County Storm Water BMP Tour Guide", Spring 2002 CHAPTER 5, ND. "INFILTRATION SYSTEMS OR BRAINS"

Christensen. E.R. and Guinn, V.P., 1979, “Zinc From Automobile Tires in Urban Runoff”, Journal of the Environmental Engineering Division, Proceedings of the ASCE, Vol.105, No. EE1, PP 165-168.

Chrispijn, J.A. 2003. “Stormwater Pollution in Sullivans Cove”, Hobart: An Unwanted By- product of Development” Hobart City Council.

Chrispijn, J.A. 2004. “Stormwater Pollution in Sullivans Cove”, Hobart: An Unwanted By- Product of Development”. Hobart City Council, Australia.

Christensten, E.R. and Guinn, V.P., 1979, “Zinc From Automobile Tires in Urban Runoff”, Journal of the Environmental Engineering Division, Proceedings of the ASCE, Vol. 105,No.EE1, pp 165-168.

Chu, L.-Y. & Chen, W.-M. 1993. “Research on the motion of solid particles in a hydro cyclone”, Sep. Sci. Techno. 28 (10) (1993)1875-1886.

Chu, L.-Y. Qin, J.-J. Chen, W.-M. & Lee, X.-Z., 2000. “Energy consumption and its reduction in the hydro cyclone separation process”. Part II. Time-averaged and fluctuating characteristics of the turbulent pressure in a hydro cyclone, Sep. Sci. Techno. 35 (15) (2000) 2543-2560.

Cialdini, R.B., Reno, R.R & Kallgren, C.A. 1990. “A focus theory of normative conduct: recycling the concept of norms to reduce littering in public places”, 58 Journal of Personality and Social Psychology, 1015-26.

Clay, H. 2001. “Stormwater Management Plan DRAFT”, Water and Sewerage, Wentworth Shire Council, April 2001

Clift, R., Grace, J.R. and Weber, M.E., 1978. “Appendix B in Bubbles, Drops and Particles”, Academic Press, New York.

Cole, W.C., and Yonge, D.R., 1993. “Sediment and Containment Removal by Dual-Purpose Detention Basins”, Washington State Transportation Centre Report, May 1993.

Cordingley, M.G., 1997, “MGS developments and strategies in fine gravity separation techniques” In Innovation in Physical Separation Technologies, Falmouth, UK: IMM, pp. 75-82.

Crowe,C.T., Sharma, M.P.. Stock, D.E.. 1977. “The particle-source-in-Cell (PS1-Cell) model for gas-droplet flow”. Journal of Fluids Engineering 112, 362-368.

Dabir, B., Petty, C.A. 1986. “Measurement of mean velocity profiles in a hydro cyclone using laser Doppler anemometry”, Chem. Eng. Common. 48 (4-6) (1986)377-388.

Dallmer, L. N D. SQIRTS- "An on-site stormwater treatment and reuse approach to sustainable water management in Sydney". South Sydney City Council, NSW, Australia.

Dempsey, B.A., Tai, Y.L. and Harrison, S.G. 1993, "Mobilisation and Removal of Contaminants Associated with Urban Dust and Dirt", Wat. Sci. Tech., Vol. 28, No. 3-5, pp. 225-230.

Department of Primary Industries, Water & Environment. Water. Algal bloom. (http://www.dpiwe.tas.gov/inter.nsf/WebPages/RPIO-4YK9Z8? open, available on 5/11/2004)

DEPARTMENT OF TRANSPORTATION. 1998. "METHOD OF SOIL AND AGGREGATE SAMPLE PREPARATION". TRANSPORTATION AND HOUSING AGENCY. September 1998

Devnanthan, N., Dudukovic, M.P., Lapin, A., Lubbert, A., 1995. "Chaotic flow in bubble column reactors". Chemical Engineering Science 50, 2661-2667.
Division of Soil and Water Conservation, Virginia. Cited at www.novaregion.org/es_pubs.htm#bmp

Drapper, D., Tomlinson, R. & Williams, P. 1999. "An investigation of the quality of stormwater runoff from road pavements: a south-east Queensland case study", pp. 1225-1232.

Drpaper et al [Source: Driscoll, E., Shelley, P.E., and Strecker, E.W.1990. "Pollutant Loadings and Impacts from Highway Stormwater Runoff". Volumes I-IV. FHWA/RD-88-006-9, Federal Highway Administration, Woodward-Clyde Consultants, Oakland, CA.

Doby, M.J., Kraipech, W., and Nowakowski, A.F. 2005. "Numerical prediction of outlet velocity patterns in solid-liquid seperators", Chemical Engineering Journal 111, pp. 173-180.

Driessen, M.G., 1984. "Trans. Am. Inst. Min" (metal.) Eng., 177, 240.

Durdan, C.A, Reeder, G.D., & Hecht, P.R., 1985. "Litter in a university cafeteria: demographic data and the use of prompts as an intervention stratigy". 17 Environments and Behaviour, 387-404.

Duncan, H.P. 1999. "Urban Stormwater Quality: A Statistical Overview", Cooperative Research Centre for Catchment Hydrology. Melbourne, Australia.

Duncan, H.P. 1997. "Urban Stormwater Treatment by Storage". 24th Hydrology and Water Resources Symposium, Auckland, New Zealand, New Zealand Hydrological Society: pp 522.

Duncan, H.N.D. "Urban Stormwater Pollutant Concentrations and Loads" Chapter 3
Eaton, A.D., Clesceri, L.S. & Greenberg, A.E. (ed.) 1995,"Standard Methods for the Examination of Water and wastewater", 19th edn, APHA,, Washington, DC.

ECORECYCLE VICTORIA. 1998. "In-Line Litter Separator: Installation and Monitoring Project". August 1998. Prepared by, Swinburne University of Technology.

Engineering Fundamentals Report SC18-02, 2000. "Application of Water-Quality Engineering Fundamentals to the Assessment of Stormwater Treatment Devices", Santa Clara Valley Urban Runoff Pollution Prevention Program. Final Technical Memorandum. 28 August 2000

Environment Australia, 2002. 'Overview of the conservation of Australian marine invertebrates"', Report for environment Australia. (http://www.amonline.net.au/invertebrates/marine_overview/chapt6as.html)

ENVIRONMENT AUSTRALIA, 2002. "INTRODUCTION TO URBAN STORMWATER MANAGEMENT IN AUSTRALIA"ISBN 0 642 548 323

ENVIRONMENT AUSTRALIA, 2002. "INTRODUCTION TO URBAN STORMWATER MANAGEMENT IN AUSTRALIA" PREPARED UNDER THE URBAN STORMWATER INITIATIVE OF THE LIVING CITIES PROGRAM. ISBN 0 642 548 323

Environmental Protection Agency, 1999. "Storm Water Technology Fact Sheet, Hydrodynamic Separators" Office of Water Washington, D.C. EPA 832-F-99-017, United States, September 1999

Escande, Camichel, Bratosin, Dobos, Szolnoky is not found in Models in Hydraulic Engineering book.

Essery, C.I. 1994. "Gross Pollutant Water Quality- Its measurement and the performance of remediation technologies/management practices", Stormwater Industry Association, Best Stormwater Management Practise, NSW.

Fan, J., Zhang, X., Chen, L., Cen, K., 1997. "Numerical simulation and experimental study of two-phase flow in a vertical pipe". Aerosol Science and Technology 27, 281-292.

Faram, M.G. and Andoh, R.Y. G. 1999. "Evaluation and Optimisation of a Novel Self-Cleansing Combined Sewer Overflow Screening System using Computational Fluid Dynamics", 8ICUSD, Sydney, Australia, August- September, 1999.

Faram, M.G. & Andoh, R.Y.G. 2000. "Application of Simulation and Predictive Techniques for the Evaluation of Hydrodynamic Separators", Wastewater Treatment:

Standards and Technologies to Meet the Challenges of the 21st Century, CIWEM/AETT Millennium Conf, Leeds, UK,4-6 April, 2000.

Faram, M.G. & Harwood, R. 2000. "CFD for the Water Industry; The Role of CFD as a Tool for the Development of Wastewater Treatment Systems", Fluent Users' Seminar, Sheffield, UK, 21-22 September, 2000.

Faram, M.G. & Harwood, R. 2002. "A Method for the Numerical Assessment of Sediment Interceptors", 3rd International Conference on Sewer Preocesses & Networks, Paris, France, 15-17 April, 2002.

Faram, M.G. Harwood, R. 2003. "Investigation Into The Sediment Removal and Retention Capabilities of Stormwater Treatment Chambers". StormCon Conference, San Antonio, Texas, USA. July 28-31.

Faram, M.G. & Harwood, R. 2002. "Assessment of the Effectiveness of Stormwater Treatment Chambers using Computational Fluid Dynamics". 9th International Conference on Urban Drainage, Portland, Oregon, USA, 9-13 September, 2002.

Ferguson, J.E. and Ryan, D.E. 1984, "The Elemental Composition of Street Dust from Large and Small Urban Areas Related to City Type", Source and Particle Size, Sci. Total Environment, Vol. 34, pp.101-116, Elsevier Science Publishers, Amsterdam.

Ferrara, G., 1960, "A process of centrifugal separation using a rotating tube" In 5th International Mineral Processing Congress, London: IMM, pp.173-184.

Ferrara, G., Prati, U., and Bevilacqua, 1991, "Fine particles wet gravity processing-prospects of separation in centrifugal field", Symposium of Fine Particle Society, San Jose, CA.

Ferrara, G., 1960. "A process of Centrifugal Separation Using the Rotating Tube", Proceedings 5th ht. Miner. Process. Cong. London: IMM 173-184 (1960).

Field, R., R. Pitt, M. Lalor, M. Brown, W. Vilkelis, and E. Thackston. 1994. "Investigation of dry-weather pollutant entries into storm-drainage systems" J. Envir. Eng. Vol.120, No.5, pp. 1044-1066. Sept./Oct 1994.

Finnie, W.C., 1973. "Field Experiments in Litter Control", 5 (2) Environment and Behavior, 123- 144.

Fisher, M., Flack, R.., 2002, "Velocity distributions in a hydrocyclone separator", Exp. Fluids 32(2002) 302-312

Fletcher, T.D., Deletic, A.B. & Hatt, B.E. 2004. "Australian Water Conservation and Reuse Research Program, A Review of Stormwater Urban Design in Australia"

Department of Civil Engineering & Institute for Sustainable Water Resources, Monash University, January 2004.

Fletcher, T.D., Wong, T.H.F., Duncan, H.P., Coleman, J.R. and Jenkins, G.A. 2001, "Managing Impacts of Urbanisation on Receiving Waters: A Decision-making Framework", proceedings of the 3rd Australian Stream Management Conference, Brisbane, 27-29 August, 2001, pp.217-223.

Fletcher, T.D., Deletic, A.B. & Hatt, B.E. 2004. "Australian Water Conservation and Reuse Research Program, A Review of Stormwater Sensitive Urban Design in Australia" Department of Civil Engineering & Institute for Sustainable Water Resources, Monash University January 2004. ISBN 0 643 09183 1

Fletcher, T.D., Duncan, H.P., Poelsma, P. And Lloyd, S.D., 003a. "Stormwater flow, quality and treatment: literature review, gap analysis and recommendations report", NSW. Environment Protection Authority and Institute for Sustainable Water Resources, Department of Civil Engineering, Monash University, Sydney.

Forssberg, E. & Nordquist, T. 1987. "Pilot Plant Trials of New Gravity Concentration Equipment". Minerals and Metall. Proc., 87-89 (May 1987)

Fox, G.O'Brien. E. 1992. "Design, Operation and Performance Monitoring of South Bondi Beach GPTs". Seminar-Wednesday 20th May 1992.

Frod, T.C. & Graham, J.M. 1991. "An introduction to Centrifugation". Department of Biology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, UK.

Galli, J., 1992. "Analysis of Urban BMP Performance and Longevity in Prince George's County", Maryland. 92711, Prince George's County Department of Environmental Resources.

GeoSyntec Consultants (Wright Water Engineers, Inc.) 2006. "Analysis of Treatment System Performance" International Stormwater Best Management Practices (BMP). Prepared for: Water Environment Research Foundation, American Society of Civil Engineers (Environmental and Water Resources, Institute/Urban Water Resources Research Council), U.S. Environmental Protection Agency, Federal Highway Administration, American Public Works Association.

Geldof, G., P. Jacobsen, and S. Fujita. 1993. "Urban stormwater infiltration perspectives." Proceedings of the 6th International Conference on Urban Storm Drainage". Edited by J. Marsalek and H.C. Torno. Niagara Falls, Ontario. September 12-17, 1993. IAWQ, London. Published by Seapoint Publishers, Victoria, B.C. pp. 963-968.

German, J. And Svensson, G. 2001, "Street Sweeping As s Pollution Control Measure", Proceedings of Novatech 2001- Innovative Technologies in Urban Drainage, Lyon, France, 25-27 June 2001, vol.1, Session S2.3, pp.383-390.

Gosman, A.D., Ideriah, F.J.K., 1976. "Teach T: a general computer program for two-dimensional, turbulent, recirculating flows. The Lecture in Imperial College.

Gupta, A.K., Lilley, D. & Syred N., 1984. "Swirl Flows, Abacus Press, Tunbridge Wells", Kent, 1984.

GONZALEZ-LOZANO, M.C., ORTIZ-GALLARZA, S.M., SALAZAR-CORIA, L. And GONZALEZ-MACIAS, M.C. 2002. "Pollution and Biological Quality Evaluation of the "Limo'n" Lagoon at Tabasco, Mexico" 9th International Symposium of the Interactions

Griffiths, W.D. & Boysan, F. 1996. "Computational fluid dynamics and empirical modelling of the performance of a number of cyclone samplers". Journal of Aerosol Science 27 (2),281-304.

Grienberger, J., Hoffman, H., 1992. "Investigations and modelling of bubble columns". Chemical Engineering Science 47, 2215-2220.

Haestad Methods, Inc. 2002. "Basic Hydraulic Principles". Chapter 1.

Hamill, L. (2001). "Understanding hydraulics", Second edition. Basingstoke, Palgrave.

Hamill, L. 2001. "Understanding Hydraulics" Flow measurement. 2nd Edition. Chapter 5.19 Oct 2001

Harwood, R. 1998. "The Influence of CSO Chamber Size on Particle Retention Efficiency Predictions", 81CUSD, Sydney, Australia, August- September, 1999.

Harwood, R. 2002. "CSO Modelling Strategies Using Computational Fluid Dynamics", 9ICUD conference, Portland, Oregon, USA.

He, P., Salcuden, M, Branion, R. & Gartshore, I.S. 1997. "Mathematical Modelling of Hydro cyclones", In The 1997 ASME Fluid Engineering Division Sumner Meeting FEDSM'97.

Harper, H.H. 1985. "Fate of Heavy Metals from Highway Runoff in Stormwater Management Systems". Ph.D. Dissertation, University of Central Florida, Orlando, F.L.

Harris, J.H., 1959. "Serial Gravity Concentration: a new Tool in Mineral Processing Trans". Inst. Min. & Metal., 69, 85-94 (Dec. 1959).

Heberlein, T.A., 1971. "Moral Norms, Threatened Sanctions and Littering Behaviour". University of Wisconsin, Madison.

Hides, S.P. 2002. "TREATMENT OF WET WEATHER DISCHARGES IN COLUMBUS", GEORGIA, USA" Portland, ME 04102. Seoul, South Korea

Hoekstra, A.J., Derksen, J.J. & Van Den Akker, H.E.A. 1999. “An experimental and numerical study of turbulent swirling flow in gas cyclones”. Chemical Engineering Science pp. 2055-2065.

Hon, S.L., Barrett, M.E., and Jr, J.M.F. 2003. “Project 0-4252-S: Process Framework for Identifying and Prioritizing Water Quality” August 2003. CENTER FOR TRANSPORTATION RESEARCH, THE UNIVERSITY OF TEXAS AT AUSTIN

Hopke, P.K., Lamb, R.E. and Natusch, D.F.S., 1980, “Multielemental Characterization of Urban Roadway Dust”, Environmental Science and Technology, Vol. 14, pp. 164-172.

Honaker, R.Q., Wang, D., and Ho, K., 1996, “Application of the Falcon concentrator for fine coal cleaning”, Minerals Engineering, 9 (11), pp. 1143-1156.

Holland-Batt, A.B., 1998, “Gravity separation: A revitalized technology” Mining Engineering, Sept.,pp.43-48.

Hsieh, K.T., Rajamani, R.K., 1991. “Mathematical model of the hydro cyclone based on physics of fluid law”. AIChE Journal 37 (5), 735-746.

Huntley, H.E. 1952. “Dimensional Analysis”. 1st ed. London : MacDonald & Co.

Hepburn, W. 2206. “Rocla VersaTrap SPT”. Perth, Western Australia
http://www.greenworks.tv/stormwater/vegetatedswales.htm
http://www.pc-education.mcmaster.ca/instrumentation/flow.htm
http://www.ascscientific.com/sieves.html
http://www.tnrcc.state.tx.us/admin/topdoc/rg/348/index.html)

Infiltration Trench TC-10, 2003. “California Stormwater BMP Handbook New Development and Redevelopment” January 2003 www.cabmphandbooks.com

Ismail Muhamed, 2008. “Two phase separation of gross pollutants using centrifugal forces”, PhD Thesis, Curtin University of Technology, Australia.

Iowa Stormwater Management Manual, 2007. “Detention Basin Outlet Structures”. Version 1, February 19, 2007.

Jago, R.A. & Davey, A.N.D. “CONTINIOUS INNOVATION- THE CDS STORY”.

Jago, R.A. and Davey, A. 2004. “Continuous Innovation_ The CDS Story”, Australia.

James, R.B., 1999. “SOLIDS IN STORM WATER RUNOFF”, Water Resources Management, April 17.

Jordan, K. 2005. “Numerical modelling of highly swirling flows in a cylindrical through-flow hydro cyclone”. SE- 100 44 Stockholm, Sweden.

Justin Lewis. 2002. "Effectiveness of stormwater litter traps for Syringe and litter removal". Report prepared for Melbourne Water Corporation. ISBN 0-7311-8871-3

Kidcadd, D., and Gyasi- Agyei, Y., N D. " MUSIC MODELLING OF LAKE CALLEMONDAH, GLADSTONE" James Goldstone Faculty of Engineering and Physical Systems, Central Queensland university, Rockhampton, Australia.

Kidd, L. Wainwright, M. 2004. "Flaggy Creek Stormwater Management Plan", Lake Macquarie City Council, Australia. R.N0817.001.01.DOC.26th Feb 2004

Kim, E, Chang, G and Yoon, J. I. 2004. "Numerical analysis of a hydro cyclone in a recirculation aquaculture system" 15th Australian Fluid Mechanics Conference, 13-17 December 2004.

Knelson, B. & Jones, R., 1994. "A new Generation of Knelson Concentrators: a Totally Secure System goes on Line". Minerals Engineering 7, (2/3), 201-207.

Knowles, S.R., Woods, D.R. & Feuerstein, I.A., 1973. "The velocity distribution within a hydrocyclone operating without an air-core", Can. J. Chem. Eng. 51 91973)263-271.

Krahforst, C & McKenna, S. Sargent, D. Knowles, R. 1999. "An Evaluation of Innovative Stormwater Treatment Technology Installations Designed to Mitigate Storm Drain Pollution Impacting Shellfish Beds at Wychmere Harbour, Harwich and the Jones River, Gloucester, Massachusetts". U.S. Environmental Protection Agency- Region I

Krauss, R.M., Freedman, J.L., & Whitecup, M., 1978. "Field and laboratory studies of littering", 14 Journal of Experimental Social Psychology, 109-122.

Krishna, R.,Urseanu, M.I., van Baten, J.M., Ellenberger, J., 1999. "Influence of scale on the hydrodynamics of bubble columns operating in the churn-turbulent regime: experiments vs. Eulerian simulations". Chemical Engineering Science 54, 4903-4911.

KYNCH, G.J. (1952). " A theory of sedimentation". Trans. Faraday Soc. 48 166-176.

Kvasnak, W., Ahmadi, G., 1996. "Deposition of ellipsoidal particles in turbulent duct flows". Chemical Engineering Science 51, 5137-5148.
Lan, L. Feng, J. Jian-ren, F. Ke-fa, C. 2004. "Recent development of vortex method in incompressible viscous bluff body flows". Journal of Zhejiang university science, ISSN 1009-3095. China.

Landphair, H. Thompspn, D. Teal, M. 2002 "RETROFITTING TxDOT DRAINANGE STRUCTURES TO IMPROVE STORMWATER QUALITY' Report 4137-2, Project Number 0-4173, Research Project Title: Feasibility of Retrofitting, Drainage Facilities to Improve Water Quality, September 2001.

Lain, S., Broder, D., Sommerfeld, M., 1999. “Experimental and numerical studies of the hydrodynamics in a bubble column”. Chemical Engineering Science 54, 4913-4920.

Lapin, A., Passchen, T., Junghans, K., Lubbert, A., 2002. “Bubble column fluid dynamics, flow structures in slender columns with large-diameter ring-spargers”. Chemical Engineering Sciences 57, 1419-1424.

Lapin,A.,Lubbert, A., 1994. “Numerical simulation of the dynamics of two phase gas-liquid flows in bubble columns”. Chemical Engineering Science 49, 3661-3684.

Laplante, A.R., 1993. “ A Comparison of two Centrifugal Concentrators”. Ann. Canadian Miner. Proc. Conf., Otta’wa, 20 (1993)

Laplante, A.R., Buonvino, M., Veltmeyer, A., Robitaille, J., and Naud, G., 1994, “A study of the Falcon concentrator”, Canadian Metallurgical Quarterly, 33 (4), pp. 279-288

Laplante, A.R., Buonvino, M., Veltmeyer, A., Robiataille, J., and Naud, G., 1994, “A study of the Falcon concentrator On Gold Recovery by Gravity McGill Short Course”, 31 (May 1993).

Laplante, A.R., 1997, “Semi-batch centrifugal concentrators”, personal communication (JKMRC).

Lewis, J. 2002. “EFFECTIVENESS OF STORMWATER LITTER TRAPS FOR SYRINGE AND LITTER REMOVAL”, Melbourne Water Corporation. ISBN 0-7311-8871-3.

Luksic, R., Edde, W. Olivieri, A. 2002. “An update of the 1999 Catch Basin Retrofit Feasibility Study Technical Memorandum”. June2002.

Livingston, E.H. 1988. “The Use of Wetlands for Urban Stormwater Management”. Design of Urban Runoff Quality Controls, Proceedings of an Engineering Foundation Conference on Current Practice and Design Criteria for Urban Quality Control, Potosi, Missouri, ASCE: 467-490.

Lawrence, A. I. 1999. “Stormwater Pollution Control Pond and Wetland Models”. Proceedings of the Eighth International Conference on Urban Storm Drainage, Sydney, Australia: pp. 1058-1065.

Lee, A.J., Taylor, S., Lee. G.F., 2000. “Stormwater Runoff Water Quality”, Science/Engineering Newsletter, Devoted to Urban Stormwater Runoff, Water Quality Management Issues. Volume3 Number 2, May 19. 2000

Li, A., Ahmadi, G., 1992. “Dispersion and deposition of spherical particles from point sources in a turbulent channel flow”. Aerosol Science and Technology 16, 209-226.

LID Centre, 2003. "Lesson 7, Vegetated Swales". (http://www.lowimpactdevelopment.org/epa03/LIDtrans/L07_Swales.pdf)

Lilge, E.O., 1962. "Hydro cyclone fundamentals", Trans. Inst. Metal. 71 (1962) 285-337.
LMNO Engineering, Research and Software, Ltd. 1999. (http://www.lmnoeng.com/Weirs/vweir.htm)

Luttrell, G.H., Honaker, R.Q., and Phillips, D.I., 1995, "Enhanced gravity separators: New alternatives for fine coal cleaning", 12th International Coal Preparation Conference, Lexington, KT, pp.281-292.

Luttrell, G.H., Honaker, R.Q., and Phillips, D.I., 1995, "Enhanced gravity separators: New alternatives for fine coal cleaning", 12th International Coal Preparation Conference, Lexington, KT, pp. 281-292.

Madge, B., 2001 "5 Effective Use of BMPs in Stormwater Management"

Majumder, A.K. and Barnwel, J.P. 2006. "Modelling of enhanced gravity concentrators-present status", Mineral processing & Extractive Metal. ISSN:0882-7508.

Malec, S.N, D. "Storm Water Management in the City of Chicago" "City of Chicago" Department of Environment Chicago, Illinois

Malhotra, A., Branion, R.M. R. & Hauptmann, E.G. 1994. "Modelling the Flow in a Hydro cyclone". Canadian Journal of Chemical Engineering 72, 953-960.

Malina, J., M. Barrett, M. Keblin, P. Walsh, and R. Charbonneau 1997. "Evaluation of the Performance of Permanent Runoff Controls", Summary and Conclusions, Bureau of Engineering Research, University of Texas;36.

Malvik, T., Sandvik, K..L. and Rein, A., 1997, "Scandinavian experiences with the Kelsey centrifugal jig", Innovation in Physical Separation Technologies, Falmouth: IMM, pp.113-122.

Makepeace, D.K., Smith, D.W. & Stanley, S.J. 1995, "Urban Stormwater Quality: Summary of Contaminant Data", Crit Rev Environ Sci Techno, vol. 25, no. 2, pp.93-139.

Manly Hydraulics Laboratory. 2004. "City sediments and Gross Solids stage Two Study" Report MHL 1281. ISBN 07347 43017. November 2004.

Manly Hydraulics Laboratory. 2004. "SQIRTS ASSESSMENT AT SOLANDER PARK, ERSKINEVILLE FINAL REPORT", Report MHL 1243. NSW Department of Commerce, ISBN 073474319 X. April 04.

Mann, R. and Hammerschmid, K. 1989. “Physical and Chemical characteristics of Urban Runoff from Two Catchments in Hawkesbury/ Nepean Basin”, Australia Water and Wastewater Association 13th Federal Convention, Canberra 6-10 March, 1989.

McAlister, S., 1992, “Case studies in the use of the Falcon gravity concentrator”, 24th Annual Canadian Mineral Processors Conference, Ottawa, ON, Canada.

McCarthy, L.G., Kosiol, C.,Healey, A.M., Bradley, G. Sexton, J.C. and Corrigan, O.I. 2003. “Simulating the Hydrodynamic Conditions in the United States Pharmacopeia Paddle Dissolution Apparatus”. March 31, 2003.

McCrystal, S. and LANT, P. 2004. “SETTLING CHARACTERISTICS OF ENRECANAEROBIC SLUDGE”, CHEE4006- INDIVIDUAL INQUIRY A. 28th MAY 2004.

McKay, P., & Marshall, M., 1993. “Backyard to Bay: The Tagged Litter Report”, Melbourne Water & Melbourne Parks and Waterways. ISBN 0 7306 3518.

McKeown, W. 1999. “Cooks River Stormwater Management Plan”, Sydney Water Corporation, Sep 1999.

Mineart, P. and S.Singh. 1994. “The Value of More Frequent Cleanouts of Storm Drain Inlets”. Watershed Protection Techniques. 1 (3): 129-130.

Mehta, A., 1986. “Characterization of Cohesive Sediment Properties and transport processes in estuaries”, In Mehta, A. (Ed), Estuarine Cohesive Sediment Dynamics, Lecture Notes in Coastal and Estuarine Studies. Springer, Berlin, pp 290-325.

Menezes, F.M. Areal, R. Luketina, D. 1996. “Removal of particles using coagulation and flocculation in a dynamic seperator’, Powder Technology 88 (1996) 27-31.
Minton, G., Leif, B., Sutherland, R., 1996, “PNW Experience with Vegetated (Bio)swales”, Stormwater Treatment Northwest, Vol.2, No.4.

Monredon, Hsieh, T.C. K.T. Rajamani, R.K. 1992. “Fluid flow of the hydro cyclone: an investigation of device dimensions”, Int. J. Miner. Process. 35 (1992) 68-83.

Mudde, R.F., Simonin, O., 1999. “Two- and three-dimensional simulations of a bubble plume usinf a two-fluid model”. Chemical Engineering Science 54, 5061-5069.

Mudgway, L.B., Duncan, H.P., McMahon, T.A. and Chiew, F.H.S., 1997, “Best Practice Environmental Management Guidelines for Urban Stormwater”. Background Report to the Environmental Protection Authority, Melbourne Water Corporation and the Department of Natural Resources and Environment, Victoria, Cooperative Research Centre for Catchment Hydrology Report 97/7, October 1997.

Musiake, K.J. Okamura, and J. Matsushita. 1990. "The urban hydrological system with shallow infiltration facilities- a case study of an area in Tokyo Metropolis", Proceedings of the 5th International Conference on Urban Storm Drainage. Osaka, Japan. July 1990. Pp. 113-118.

MUSIC Development Team, 2005. "CRC for Catchment Hydrology", Revised February 2005 for Version 2.1

Nakayama, Y. & Boucher, R.F. 1999. "Introduction to Fluid Mechanics", ISBN 0 340 67649 3.

Nakayama, Y. & Boucher, R.F. 1999. "Introduction to Fluid Mechanics". Civil Engineering Hydraulics. ISBN 0 340 67649 3.

Nakayama, Y. Boucher, R.F. 2000. "Introduction to Fluid Mechanics". "Measurement of Flow Velocity and Flow Rate". Chapter 11.

Nalluri, C., & Featherstone, R.E. 2006. "Civil Engineering Hydraulics". Fourth Edition.
New Jersey Stormwater BMP Manual. 2004. "Chapter 9.6: Standard for Manufactured Treatment Devices", February 2004.

Nielson, J.S. and Carleton, M.G., 1989. "A Study of trash and trash interceptions devices on the Cooks River Catchment", Sydney, Proceedings of the Australian Water and Wastewater Associations 16th Federal convention, I.E. Australia, ACT, Australia.

Nilson, B., Silby, N. And Argue, J.R. (1997). "An Investigation into Source Control of Gross Pollution", Submitted at the 8th National Local Government Engineering Conference.

NSW EPA (2000). "News Release: Contamination Dropping But Environment Still Threatened".

North Caroline Department of Natural Resources and Community Development (NCDNRCD) 1993, "An Evaluation of Street Sweeping as a Runoff Pollution Control", EPA Publication, PB85-102507.

Novak, P and Cabelka, J. 1981. "Models in Hydraulic Engineering. Physical Principles and Design Applications). ISBN 0-273-08436-4.

Nova Tec Consultants Ltd. 2003 "Effluent flow measurement". PART E- WATER AND WASTEWATER SAMPLING".

Okamoto, Y., Konugi, M. and Tsuchiya, H. "Numerical Simulation of the Performance of a Hydrodynamic Seperator", 9ICUD conference, Portland, Oregon, USA, 2002.

Onondaga Country Department of Water Environment Protection. 2002. “Lake improvement” ORANGE COUNTY STORMWATER PROGRAM APPENDIX E2 TRASH AND DEBRIS BEST MANAGEMENT PRACTICE (BMP) EVALUATION June 2003

O’Brien, E.J. 1994. “Water Quality Changes Associated with the Installation of the Bondi Gross Pollutant Traps”, Proceedings of the Australian Water and Wastewater Associations 16th Federal Convention, I.E. Aust., ACT, Australia.

PATA WALONGA CATCHMENT WATER MANAGEMENT PLAN. Issues and Options for their Management. Peck, O.B.., US. Pat 444, 619. (1891). Pennsylvania Stormwater Management Manual, N.D. “Section 5- Structural BMPs”

Peluso, V.F., Marshall, P.E. A. 2002. “Best Management Practices for South Florida Urban Stormwater Management Systems”. TECHNICAL PUBLICATION REG-004

Perrens, S.J., Phillipis, B.C. and Lyall, B. 1991. “Options for Stormwater Quality Management- Examples at Bondi Beach”, Proceedings, International Hydrology and Water Resources Symposium, 1991, IEAust. Natl. Conf. Pub. 91/19,2-4 October, Perth, pp. 531-536.

Perrens, S.J. and Liddle B.G. 1991. “Design of stormwater Sediment and pollution Control Structures”, Stormwater Quality Control in Tuggerah Lake Seminar, Institution of Engineers Australia.

Pfleger, D., Gomes, S., Gilbert, N., Wagner, H.-G., 1999. “Hydrodynamic simulations of laboratory-scale bubble columns fundamental studies of the Eulerian- Eulerian modelling approach”. Chemical Engineering Science 54,5091-5099.

Pezzaniti, D. Jhonston, L. 2000 “Rocla Cleans All Monitoring Assessment Progress Report”, Reported for Rocla Pipeline Products. Urban Water Resources Centre, University of South Australia, March, 2000.

Phillips, D.I. (1999). “A New Litter Trap for Urban Drainage Systems”. Water Sci. Technol. (G.B.), 39, 2,85.

Phillipis, B.C. and Lawrence, A.I. 1990. “Urban Stormwater Management- A Quality of life Issue”, Proceedings, international Symposium on Urban planning and Stormwater Management, 28 May- 1 June, Kuala Lumpur.

Pitt, R.E. and Shaeley, G. (1982). “A Demonstration of Non- Point Source Pollution Management on Castro Valley Creek”, Alameda County Flood Control and Water Conservation District, Hayward, California.

Pitt, R.E. and Amy, G. (1973). “Toxic Materials Analysis of Street Contaminants”, USEPA Washington DC Report No, EPA-R2-73-283.

Pitt, R.E. and Bissonnette, P. (1984). “Bellevue Urban Runoff Program: Summary Report”, Prepared for the Nationwide Urban Runoff Program (NURP), Water Planning Division, U.S. Environmental Protection Agency.

Pierson, W. (1981) “Solids- Liquid Separation”, Chapter 20, Second Edition, L. Svarovsky (Ed), Butterworth.

POST-CONSTRUCTION RUNOFF CONTROLS, 2006. “Second Edition Stormwater Management Standards Manual”, CHAPTER 5, Draft 02/25/2006

PRICE, F.A. YONGE, D.R.N D. “ENHANCED CONTAMINANT REMOVAL IN STORMWATER DETENTION BASINS BY COAGULATION” Department of Civil and Environmental Engineering, Washington State University.

Ranade, V.V., 1992. “Flow in bubble column: some numerical experiments”. Chemical Engineering Science 47, 1857-1869.

Reinelt , Lorin E., Horner, Richard R. 1995. Pollutant removal from stormwater runoff by palustrine wetlands based on comprehensive budgets”, Ecological Engineering 4 (1995)

Renko, E.K. 1998. “Modelling hindered batch settling Part II: A model for computing solids profile of calcium carbonate slurry’. ISSN 0378-4738= Water SA Vol. 24 No. 4 Oct.

RENOVATING POST- INDUSTRIAL LANDSCAPES: THE NORTH DELAWARE RIVERFRONT, field operations.

Riverside County Printing Services, 1996. “SELECTION AND DESIGN OF STORMWATER QUALITY CONTROLS”, ATTACHMENT TO SUPPLEMENT “A” OF THE RIVERSIDE COUNTY DRAINAGE AREA MANAGEMENT PLANS, April 1996

Roberson, J.A. and Crowe, C.T. 1980. “Engineering Fluid Mechanics”. Second ed. Boston: Houghton Miffin, 1980.

Rocla Pty Limited 2002. “Rocla Water Quality, CleansAll Gross Pollutant Trap”
Rocla Pty Ltd., 2004. “Rocla Water Quality, CelansAll Gross Pollutant Trap”

Rosted Petersen, C.O., P. Jacobsen, P.S. Mikkelsen. “Design for stormwater infiltration for reduction of combined sewer overflow (CSO)” Water Science and Technology, Vol. 30, no.1, pp. 53-61. 1994.

Rushton, A. Ward, A.S. and Holdich, R.G. 2000. “Solids-Liquids Filtration and Separation Technology”. Second, Completely Revised Edition.

Sansalone, J.J., et al. "Physical Characteristics of Urban Roadway Solids Transported During Rain Events", ASCE Journal of Environmental Engineering, Vol. 124, No. 5, 1998.

Sansalone J.J, Koran, J.M. Smithson J.A and Buchberger S.G. 1997. "Characterisation of Solids Transported from an Urban Roadway Surface", Proceedings of the Water Environment Federation, 70th Annual Conference, Chicago, Illinois, U.S.A. October 18-22, Vol 4.

Sanyal, J., Vasquez, S, Roy, S., Dudukovic, M.P. 1999. "Numerical simulation of gas-liquid dynamics in cylindrical bubble column reactors". Chemical Engineering Science 54,5071-5083.

Sartor, J.D. and Boyd, G.B. 1972. "Water Pollution Aspects of Street Surface Contaminants", EPA- R2-72-081, U.S. Environmental Protection Agency, 1972.

Sartor, J.D. and Gaboury, D.R. "Street Sweeping as a Water Pollution Control Measure: Lesson Learnt Over the Last Ten Years", Sci. Total Environ. 33: 171-183, 1984.

Schueler, T.R. July 1987. "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs". Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T. Et al. 1992. "A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone".

Schwarz, T. And Wells, S. (1999) "Storm Water Particle Removal using Cross-Flow Filtration and Sedimentation in Advances in Filtration and Separation Technology", Volume 12, ed. by W. Leung, American Filtrations and Separations Society, pp. 219-226.

Settle, S., Wilson, J. And Partners Pty Ltd. N D. "Treatment Trains for Stormwater Quality Improvement"

Shaheen, Donald G. 1975. "Contribution of Urban Roadway Usage to Water Pollution". EPA-600/2-75-004

Shank, G.V. 1996. "Pilot Scale Design and Demonstration of a Filter System for Adsorption of Oil and Grease in Urban Runoff", A thesis submitted in partial satisfaction of the requirements for the degree Master of Science in Civil Engineering.

Sharpin, M. G., and Harbidge, S. T. (1994). *Pollutant Removal in the Upper Stranger Pond: A Preliminary Review.* Paper presented at the Soil and Water Management for Urban Development.

Shatwell, T., and Cordery, I. (1998). *A Phosphorus and Sediment Balance of an Urban Pond.* Paper presented at the HydraStorm 98, 3rd International Symposium on Stormwater Management, Adelaide, South Australia.

Shaw L. Yu, PhD. Faculty Research Scientist Monika D. Stopinki. 2001 “TESTING OF ULTRA-URBAN STORMWATER BEST MANAGEMENT PRACTICES”, Graduate Research Assistant, Charlottesville, Virginia, January 2001, VTRC 01-R7

Shaw L. Yul, M.ASCE, Xiao Zhang2, Andrew Earles2, and Mark Sievers2 “Field Testing of Ultra-urban BMP’s”

Shaw L. Yu, Monika D. Stopinski and Jenny X. Zhen “Field Monitoring and Evaluation of Stormwater Ultra-Urban BMP’s” Graduate Research Assistants, Dept. of Civil Engineering, Univ. Of Virginia, Charlottesville, VA 22903

Shatwell, T., and Cordery, I. (1998). *A Phosphorus and Sediment Balance of an Urban Pond.* Paper presented at the HydraStorm 98, 3rd International Symposium on Stormwater Management, Adelaide, South Australia.

Shin M.S, Kim H.S and Jang, D.S, 2005. “A numerical experimental study on a high efficiency cyclone dust separator for high temperature and pressurized environments” Available online at www.sciencedirect.com

Sim, R.L. & Webster, J.L. 1992, “Performance of Trash Rack on Cup and Saucer Creek Stormwater Channel”, International Symposium on Urban Stormwater Management, Sydney, pp. 143-145.

Slack, M.D., Del Porte, S. & Engelman, M.S. 2004. “Designing Automated Computational Fluid Dynamics Modelling Tools for Hydro cyclone Design”, Minerals Engineering 17 (5), 543-547.

Smith, P. 2002. “Stormwater Monitoring; Beyond Data Collection, A Tool for Behavioural Change and Water Quality Improvements”, School of Environment and Agriculture, University of Western Sydney (UWS), Richmond 2758.

Sediment Management, WWFMP Type, N. D: “End-of-Pipe Controls, Primary Mechanism: Limit Supply or Alter Transport, Storage and Deposition”.

Somes, N.L. G., Person , J. And Wong, T.H.F. (1998). “Influence of Wetland Design Parameters on the Hydrodynamics of Stormwater Wetlands”, Hydra Storm 98, 3rd International Symposium on Stormwater Management, Adelaide, South Australia, IEAust: pp 123-128.

Standard Attachment 23.01, 2002. “Chapter 23: Detention Basin Standards”, City of Champaign Manual of Practice”, March 2002.

Stahre P and Ubonas B (1990)"Stormwater Detention for Drainage, Water Quality and CSO Management".

Stenmark, C. "Local infiltration of urban storm water in cold climate" Proceedings of the 5th International Conference on Urban Storm Drainage. Osaka, Japan. July 1990.pp.809-814. 1990.

Stenstrom, MK; Silverman, G; Bursztynsky, T A; Zarzana, A L; Salarz, S E. (1982). 'Oil and Grease in Stormwater Runoff", California Univ. Los Angeles. Dept. of Engineering Systems. Report, February 1982. Association of Bay Area Governments, Berkley, California

Stephen, F. 2005. "Impact analysis of urban stormwater metals and PAH contamination on two EAST TEXAS CREEKS", Austin State University. July 28, 2005.

Sim, R. L., and Webster, J. L. (1992). *Performance of Trash Rack on Cup and Saucer Creek Stormwater Channel.* Paper presented at the International Symposium on Urban Stormwater Management, Sydney.

Spinks, A. T., Coombes, P. J., Dunstan, R. H., and Kuczera, G. (2003, 10-14 November, 2003). *Water Quality Treatment Processes in Domestic Rainwater Harvesting Systems,* Paper presented at the 28th Hydrology and Water Resources Symposium.

Stewart, J., and Hackney, P. (2002). *Water quality of stormwater treatment wetlands at Riverside Park, Chipping Norton.* Liverpool, NSW: Liverpool City

Strecker, E. W., Kersnar, J. M., Driscoll, E. D., and Horner, R. R. (1992). *The Use of Wetlands for Controlling Stormwater Pollution.* Washington, DC: Terrene Institute.

Terstriep, M. L., Noel, D. C., and Bender, G. M. (1986). *Sources of Urban Pollutants - Do We Know Enough?* Paper presented at the Urban Runoff Quality - Impact and Quality Enhancement Technology, Proceedings of an Engineering Foundation Conference, New Hampshire, USA.

Tollner, E. W., Barfield, B. J., and Hayes, J. C. (1982). *Sedimentology of erect vegetal filters. Journal of the Hydraulics Division,* Proceedings of the American Society of Civil Engineers, 108(12), 1518-1531.

Tollner, E. W., Barfield, B. J., Haan, C. T., and Kao, T. Y. (1976). Suspended sediment filtration capacity of simulated vegetation. *Transactions of the American Society of Agricultural Engineers,* 19(4), 678-682.

Torno, H. C. (1984). *The Nationwide Urban Runoff Program.* Paper presented at the Proceedings of the Third International Conference on Urban Storm Drainage, Goteborg, Sweden.

Urbonas, B. R. (1993). *Assessment of BMP Use and Technology Today.* Paper presented at the Proceedings of the Sixth International Conference on Urban Storm Drainage, Niagara Falls, Ontario, Canada.

Urbonas, B. R. (1995). Recommended Parameters to Report with BMP Monitoring Data. *Journal of Water Resources Planning and Management,* 121(1), 23-34.

Uusi-Kamppa, J., Turtula, E., Hartikainen, H., and Ylaranta, T. (1996). *The interactions of buffer zones and phosphorus runoff.* Paper presented at the Buffer zones: Their processes and potential in water protection, Harpenden, Hertfordshire. United Kingdom.

Veenhuis, J. E., Parrish, J. H., and Jennings, M. E. (1988). *Monitoring and Design of Stormwater Control Basins.* Paper presented at the Design of Urban Runoff Quality Controls, Proceedings of an Engineering Foundation Conference on Current Practice and Design Criteria for Urban Quality Control, Potosi, Missouri.

Victorian Stormwater Committee. (1999). *urban stormwater: best practice environmental management guidelines.* Melbourne: CSIRO Publishing.

Wong, T. H. F. (2002). *Recent Advances in Australian Practice on the Use of Constructed Wetlands for Stormwater Treatment.* Paper presented at the 9th International Conference on Urban Drainage (Extended Abstracts), Portland, Oregon, USA.

Wong, T. H. F. (Ed.). (2003). *Australian runoff quality.* Sydney, Australia: Institution of Engineers, Australia.

Wong, T. H. F., and Geiger, W. F. (1997). Adaptation of wastewater surface flow wetland formulae for application in constructed stormwater wetlands. *Ecological Engineering,* 9, 187-202.

Wong, T. H. F., Breen, P. F., and Lawrence, I. (2003). Constructed wetlands and ponds. In T. H. F. Wong (Ed.), *Australian Runoff Quality.* Sydney, Australia: Institution of Engineers, Australia.

Wong, T. H. F., Breen, P. F., and Lloyd, S. D. (1999a). *Retrofitting urban drainage systems for integrated stormwater management.* Paper presented at the Comprehensive Stormwater and Aquatic Ecosystem Management - First South Pacific Conference, 22-26 February, 1999 Auckland, New Zealand.

Wong, T. H. F., Breen, P. F., Lloyd, S. D., Walker, T., Dahnke, B., and Wootton, R. (2000). *Suspended solids removal in stormwater wetlands: Quantifying the role of aquatic macrophysics.* Paper presented at the 7th International Conference on Wetlands for Water Pollution Control, Florida.

Wong, T. H. F., Duncan, H. P., Fletcher, T. D., Jenkins, G. A., and Coleman, J. R. (2001, 27-29 June 2001). *A unified approach to modelling urban stormwater treatment.* Paper presented at the Second South Pacific Stormwater Conference, Auckland.

Wong, T. H. F., Fletcher, T. D., Duncan, H. P., Coleman, J. R., and Jenkins, G. A. (2002). *A model for urban stormwater improvement conceptualisation.* Paper presented at the 9th International Conference on Urban Drainage, Portland, Oregon.

Wong, T. H. F., Lloyd, S. D., and Breen, P. F. (2000). *Water sensitive road design - design options for improving stormwater quality of road runoff,* Technical Report 00/1. Cooperative Research Centre for Catchment Hydrology, Melbourne, Australia.

Wong, T.H.F. and Geiger, W.F. 1997, 'Adaptation of Wastewater Surface Flow Wetland Formulae for Application in Constructed Stormwater Wetlands', Ecol Eng, vol. 9, pp. 187-202.

Wong, T.H.F., Rodder, A. and Geiger, W.F. (1999b), 'Predicting the Performance of a Constructed Combined Sewer Overflow Wetland', Proceedings of the Eighth International Conference on Urban Storm Drainage, Sydney, Australia, vol. 4, ed. I.B. Joliffe and J.E. Ball, pp. 1947-1954.

Yousef, Y. A., Hvitved-Jacobsen, T., Wanielista, M. P., and Harper, H. H. (1987). Removal of Contaminants in Highway Runoff Flowing Through Swales. *The Science of the Total Environment,* 59, 391-399.

Yousef, Y. A., Wanielista, M. P., and Harper, H. H. (1985). Removal of Highway Contaminants by Roadside Swales. *Transportation Research Record* (1017), 62-68.

9. 1. APPENDICES

APPENDIX (A)

LITERATURE REVIEW APPENDIX

SELECTING LITTER TRAPS (selected from different sources)

Selecting a litter trap for stormwater installations can be a confusing task with many claims by vendors and numerous issues to consider. This guide is intended to provide assistance to Melbourne Water staff for the selection of litter traps for stormwater.

Concern for the impacts of stormwater gross pollutants (litter and organic material), particularly for litter has increased in recent times. There has been some research carried out in Melbourne on its characteristics and transport mechanisms, some relevant findings are:

- Approximately 100,000 m^3 (including 1 billion litter items) of gross pollutants reach Melbourne's waterways annually;
- Stormwater gross pollutants are composed of approximately 20% litter (plastic, paper and metal) and 80% organic material (such as leaves and twigs);
- The most amount of gross pollutants are carried during times of the highest flows;
- Less than 20% of litter is transported as floating material, the remainder is either entrained in the flow or sinks;
- Commercial areas contribute the most amount of litter to the stormwater system; and
- There are a range of techniques available for removing litter. The most effective strategies involve a combination of non-structural measures (e.g. education and waste management programs, and source controls) and structural treatments.

This document focuses on structural treatments to reduce litter loads in stormwater (litter traps). The location for a litter trap is also a complex issue and readers are referred to the Urban Stormwater Best Practice Environmental Management Guidelines (Stormwater Committee, 1999) for guidance. In addition, to investigate litter loads from different areas for the purpose of selecting a location for a trap, readers are referred to the decision-support-system for determining effective trapping strategies for gross pollutants developed by the Cooperative Research Centre for Catchment Hydrology (CRCCH, 1998). Selecting a litter trap

The decision of which type (and brand) of trap to select is a trade-off between the life cycle costs of the trap, the expected pollutant removal performance in regard to the values of the downstream water body and any social or political considerations.

1. LIFE CYCLE COSTS VS. POLLUTANT REMOVAL PERFORMANCE

This guide provides a method to estimate the life costs and pollutant removal rates.

The final decision on which particular device should be selected should be made by committee with open debate. It should include one person from Operations, a project manager and one other person (e.g., from Waterways and Environment or Asset Management). The discussion should include the issues covered in this document.

2. LIFE CYCLE COSTS

Life cycle costs are a combination of the installation and maintenance costs. To determine the life cycle costs the estimated duration of the project needs to be determined (eg. 20 or 25 years) or if the trap is to control pollutants during the development phase only it may be 3-10 years.

This is used to extrapolate the annual operating costs to project life costs. Below are more details on estimating the costs.

To estimate the life cycle costs for a litter trap the installation costs and the annual operating costs (for the project duration) are combined.

This can be simply performed for all traps and then, with consideration to the other influences (social, political etc.), the most appropriate trap can be selected.

To estimate life cycle costs:

Determine the project life (*n*: years)

1. Estimate the installation cost (including supply, installation and ancillary works)

Estimate the annual operating cost (including collection and disposal)

Estimate the Equivalent Annual Cost by estimating the Net Present Cost of the project and dividing by the project duration

NPC ($) = **Installation** ($) + [**n x annual maintenance** ($)]

EAC ($/year) = **NPC** ($)/ **duration** (years)

3. INSTALLATION COSTS

To estimate the installation costs there a number of local issues that will need to be considered. These include the:

- design flow rate,

size and configuration of the trap (with regard to site constraints),

- hydraulic impedance and the requirements for operation and maintenance, and
- safety and other construction issues.

If any of the below factors can not be adequately satisfied by a particular trap it should be deemed as potentially inappropriate for that location.

4. DESIGN FLOWS

Every litter trap should be designed with provision for a high flow by-pass system. The purpose of the by-pass is to protect the operational integrity of the trap during floods, ensure no flooding is caused by the trap and to prevent excessive scour of collected pollutants from within a trap.

The trap should be designed for between Q 3-months and Q 1-year, with the operation of the by-pass once these flows are exceeded (refer to Best Practice Guidelines for more details). A rule-of-thumb method for approximating more frequent flows from Q-5 values (which should be available for most minor drainage systems) has been developed for Melbourne, these are:

- Q –3 months = 0.20 x Q –5 years,
- Q –6 months = 0.33 x Q –5 years, and
- Q –1 year = 0.50 x Q –5 years.

* note that these relationships are only valid for Melbourne rainfall conditions

5. SIZE OF THE UNIT (FOOTPRINT, DEPTH)

The size of litter traps varies considerably and this will need to be accommodated by the potential location for the trap. Things to consider when assessing the size of traps include:

- the required footprint,
- the depth of excavation (to the bottom of the sump in some cases) – rock can substantially increase the installation costs,
- the sump volume required, and
- the location of any services.

6. HYDRAULIC IMPEDANCE/ REQUIREMENTS

Some litter traps require particular hydraulic conditions in order to operate effectively, for example some traps require a drop in the channel bed for operation. Requirements such as these can affect which traps may or may not be suitable in a particular area.

Other considerations are possible upstream impacts on flow and the hydraulic gradeline due to the installation of the trap. This can increase the flooding risks and all traps should be designed to not increase the flooding risk during high flows. Therefore if a trap increases the flooding risk above acceptable limits it may not be considered further.

7. OTHER CONSTRUCTION ISSUES

For each specific location there will be a number of other considerations and points of clarification that may sway the decision on which trap may be the most suitable, these include:

- Does the cost of the trap include supply and installation or just supply - if so how much is installation likely to cost?
- Does the cost include any diversion structures that will be required?
- Is specialist equipment required for installation (eg. special formwork, cranes or excavators) and what cost implications do this have?
- Is particular below ground access required, will ventilation and other safety equipment be needed – at what cost?
- Will the trap impact on the aesthetics of an area – will landscape costs be incurred after the trap installation - if so how much?
- Are there conflicts with other services at the site (eg. sewer, water, power or phone lines) and what are the cost implications of these?
- Will the trap be safe from interloper or misadventure access?
- Do the lids/covers have sufficient loading capability (particularly when located within roads) – what is the cost of any increase in load capacity and will it increase maintenance costs?
- Will the trap be decommissioned (eg. after the development phase) and what will this cost – what will remain in the drainage system?
- Are there tidal influences on the structure and how will they potentially affect performance or construction techniques?
- Will protection from erosion be required at the outlet of the device (particularly in soft bed channels), and what cost implications are there?

8. MAINTENANCE COSTS

Maintenance costs can be more difficult (but are sometimes the most critical variable) to estimate than the installation costs. Variances of the techniques used, the amount of material removed and the unknown nature of the pollutants exported from a catchment. In many cases maintenance costs are the most significant cost of a treatment measure. It is therefore imperative to carefully consider the maintenance requirements and estimated costs when selecting litter traps.

One important step is to check with previous installations by contacting the owners and asking their frequency of cleaning and annual operation costs (vendors can usually supply contact information).

All maintenance activities should be developed that require no manual handling of collected pollutants because of safety concerns with hazardous material.

Below is a list of maintenance considerations that should be applied to all litter traps. They are divided into the maintenance equipment, ancillary works, disposal of collected pollutants and safety issues.

9. MAINTENANCE EQUIPMENT REQUIREMENTS

- Is special maintenance equipment required? e.g. large cranes, vacuum trucks or truck-mounted cranes. Does this equipment need to be bought or hired - at what cost?
- Is special inspection equipment needed (e.g. access pits)?
- Are any services required (e.g. wash-down water, sewer access)?
- Are there overhead restrictions such as power lines or trees?
- Does the water need to be emptied before the pollutants - if so how will it be done, where will it be put and what will it cost?
- Can the device be isolated for cleaning (especially relevant in tidal areas)?

10. CONSTRUCTION ADDITIONS FOR MAINTENANCE

- Are road closures required and how much disturbance will this cause?
- Are special access routes required for maintenance (e.g., access roads or concrete pads to lift from) – and what are these likely to cost?

- Is there a need for dewatering areas (e.g. for draining sump baskets)?

11. DISPOSAL COSTS

Disposal costs will vary depending on whether the collected material is retained in wet or dry conditions (i.e. either under water or left so it can drain). Handling of wet material is more expensive and will require sealed handling vehicles.

- Is the material in a wet or dry condition and what cost implications are there?
- Are there particular hazardous materials that may be collected and will they require special disposal requirements (e.g. contaminated waste –what cost implications are there?
- What is the expected load of material and what are the likely disposal costs?

Loads can be estimated using the decision support system developed by the CRCCH (see references) which requires rainfall and land-use information. In the event there are no other data, the values in following table should be adopted for Melbourne conditions. Note that litter and gross pollutants (litter and vegetation) are listed, this is because the disposal costs are dependent on the gross pollutant load rather than just the litter component. No litter traps can distinguish between litter and organic material therefore, in order to remove litter they must also collect debris in the same way.

Gross pollutant loads should be used to estimate disposal costs.

APPROXIMATE LITTER & GROSS POLLUTANT LOADING RATES FOR MELBOURNE

LANDUSE TYPE	LITTER[1] Volume (Litre/ha/year)	LITTER[1] Mass[2] (kg/ha/year)	GROSS POLLUTANTS[3] Volume (Litre/ha/year)	GROSS POLLUTANTS[3] Mass[2] (kg/ha/year)
Commercial	210	56	530	135
Residential	50	13	280	71
Light-industrial	100	25	150	39

[1] litter is defined as anthropogenic materials larger then 5 mm

[2] mass is a wet mass, i.e. the mass expected when removed from a litter trap

[3] gross pollutants contain vegetation as well as anthropogenic litter (not sediments)

- Do existing installations of a particular trap have comparable maintenance costs to the estimate above? – if not should an adjustment be made?

12. OH&S

- Is there any manual handling of pollutants and what will safety and equipment cost?
- Is entering the device required for maintenance and operating purposes – will this require confined space entry? What cost implications does this have on the maintenance cycle (for example, minimum of three people on site, safety equipment such as gas detectors, harnesses, ventila0tion fans and emergency oxygen)
- Are adequate safety features built into the design (e.g. adequate step irons and inspection ports) or will these be an additional cost?

13. POLLUTANT REMOVAL EFFICIENCIES

The removal rate of litter is the primary function of a litter trap and should be estimated from previous independent testing and compared between different types of traps.

14. TARGET LITTER REMOVAL RATE

To objectively assess various pollutant traps criteria need to be developing that outline the aims of the litter trap. These can range from reducing:

- just floating visible litter,
- a proportion (e.g. 70%) of all litter,
- a proportion (e.g. 70%) of all litter and organic material, or
- just one component of the litter (e.g. sharps).

Melbourne Water generally has the objective of either reducing 70% of the litter load in a catchment, or capturing litter greater than 20 mm with treatment of all flows up to at least Q-3 months. These objectives may vary depending on the beneficial uses and threats to a receiving water body.

15. LITTER TRAP REMOVAL RATES

There are many claims by vendors on their respective removal rates for litter and other constituents. It is recommended to check any claims, ensure testing is independent and refer to the Best Practice Guidelines for removal rates estimates when no data are available.

16. ADDITIONAL POLLUTANT REMOVAL

A litter trap will be one component of a strategy to improve stormwater quality. A Stormwater Management Plan (SWMP, developed for each Local Government area) should identify the threats to waterways, the pollutants and remedial works to reduce the threats. The selection and location of a litter trap should always be consistent with and compliment the objectives set out in the SWMP.

With the SWMP in mind, it is important to recognise that some litter traps have the additional benefit of reducing other non-litter pollutants such as organic material, and some sediment. Should the SWMP identify these as causing a threat to waterways then preference may be given to those traps.

Contrary to the above point is the possibilities of a litter trap releasing pollutants during dry weather flows (i.e., it collects pollutants during storms and then trickle flows flush some pollutants from the trap – potentially in a changed form). This can be of particular concern with devices that retain pollutants in a wet sump for extended periods. Careful consideration of any performance studies and consultation with owners of existing traps is the most efficient way to explore this issue.

17. ADDITIONAL CONSIDERATIONS

The selection of a litter trap can also depend on social and political considerations. These should be taken into account on a case by case basis. Influences may include:

- Potential odour concerns at a location,
- Likelihood of pests and vermin such as mosquitoes or rats,
- Impact on the aesthetics of an area,
- Education and awareness opportunities,
- Potential trapping of fauna (e.g. turtles, eels and fish), and
- Political boundaries for funding.

18. COSTING SHEET – SELECTING LITTER TRAPS

Costs estimates for the life cycle of all litter traps considered should be performed. The next page is a check-list to help identify all costs that may be involved during the life span of the trap. This total life cost can then be compared between different traps and the most suitable trap selected, also with consideration to the pollutant removal performance.

LIFE CYCLE COSTS CHECKLIST

INSTALLATION

Does the trap satisfy: YES NO

- the design flow rate € €
- the available space constraints € €
- hydraulic and flooding issues € €
- other concerns (safety, aesthetics, etc.) € €

if any of the above questions were NO then go no further with that trap.

Trap cost $ ______________

Installation costs (if not include in supply) $ ______________

Other costs (rock excavation, lid loading, access road for maintenance etc.) $ ______________

TOTAL INSTALLATION COSTS $ ______________

MAINTENANCE

	YES	NO
Is a maintenance contract included in the proposal?	€	€

If YES… What is the annual maintenance cost? $

____

What are the expected costs of disposal? $

____

TOTAL MAINTENANCE COSTS $ _____________

IF NO…

Cost of special maintenance equipment (cranes, trucks, pumps etc.)$

____

Cost of maintenance (including frequency, time, crew etc.) $

____

Estimated disposal costs (regard to expected loads and material type)

$ _____________

Safety requirements (safety equipment hire, additional site equipment)

$ _____________

TOTAL MAINTENANCE COSTS $ _____________

EQUIVALENT ANNUAL COST

Life cycle costs = $\frac{\text{Installation costs} + (n \times \text{Maintenance costs})}{n}$ where n = project duration (years)

CHECKLIST FOR SELECTING A GPT

This checklist has been designed to help stormwater managers identify relevant issues related to the purchase of a gross pollutant trap.

	YES	NO
1. GENERAL		
• Is space available for the device (i.e. required footprint, access routes, services)?	☐	☐
• Does the location suit catchment treatment objectives (e.g. position in a treatment train)?	☐	☐
• Is the holding chamber suitable (wet or dry retention)?	☐	☐
• Are there sufficient safety precautions (i.e. preventing entry, access for cleaning)?	☐	☐
• Is the visual impact satisfactory (and odour potential)?	☐	☐
• Is the treatment flow sufficient to meet treatment objectives?	☐	☐
• Has the flooding impact been satisfactorily addressed?	☐	☐
• Has sufficient consultation taken place with operational staff and the local community?	☐	☐
• Is the expected pollutant removal rate sufficient to meet treatment objectives (consult with owners of existing installations if required)?	☐	☐
2. INSTALLATION		
• Does the price include installation?	☐	☐
• Are there sufficient contingencies for ground conditions (e.g. rock, shallow water table, soft soils etc.)?	☐	☐
• Have relocation of services been included?	☐	☐
• Are sufficient access or traffic management systems proposed as part of construction?	☐	☐
What are the cost implications of these points?	$______________	
3. MAINTENANCE		
• Is the method of cleaning applicable to local conditions (eg. OH&S issues, isolation of the unit from inflows etc.)?	☐	☐
• Are the maintenance (cleaning) techniques suitable for the responsible organisation (i.e. required equipment, space requirements, access, pollutant draining facilities etc.)?	☐	☐
• Is a maintenance contract included in the proposal?	☐	☐
• Is the size of the holding chamber sufficient (for a maximum of 12 cleans per year)?	☐	☐
• Have disposal costs been accounted for?	☐	☐
What are the cost implications of these points?	$______________	

1. TIPS TO PREVENT STORMWATER POLLUTION (SELECTED FROM DIFFERENT SOURCES)

Washing your car

Wash your car on a grassed area rather than on the road. That way the detergents and dirt will not run down the road and into a stormwater drain.

Fixing your car

If you are fixing your car at home do not tip engine oil into stormwater drains. Check with your local council regarding chemical collection services. Also make sure your car is regularly maintained so it does not leak oil or petrol.

Composting

An alternative to allowing leaves or garden clippings to accumulate in gutters or driveways is to sweep them up and start a compost heap or use them in your garden as mulch. This way you will prevent them entering the street drain where they can cause pollution.

Put litter in a bin

Make sure all your litter ends up in a bin. Litter dropped in our streets ends up in our street drains and is transported to our waterways following rain.

Paint brush cleaning

Rinse paint brushes in the laundry trough or garden rather than letting the contaminated water flow into the street stormwater drain. Tip or wipe excess paint on brushes onto newspaper or a rag. Allow to dry and then place this waste in a bin.

Cleaning the footpath

Always sweep rather than hose your footpath and place waste in the bin. Hosing with water carries dirt, soil or other waste into the street drains.

Pick up dog droppings

Always clean up after your animals. Dog dropping left in our streets ends up in our street drains and is transported to our waterways following rain.

Avoid using weed killers close to rain period or in wind

Landscape using native pants

Native plants are more suited to Australian conditions and require less water and fertilisers.

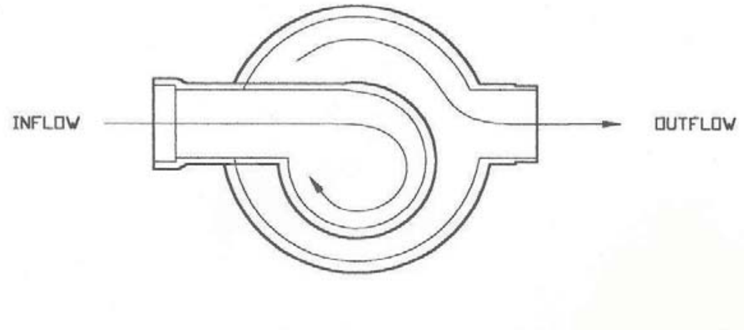
APPENDIX (B)

PHYSICAL MODEL APPENDIX

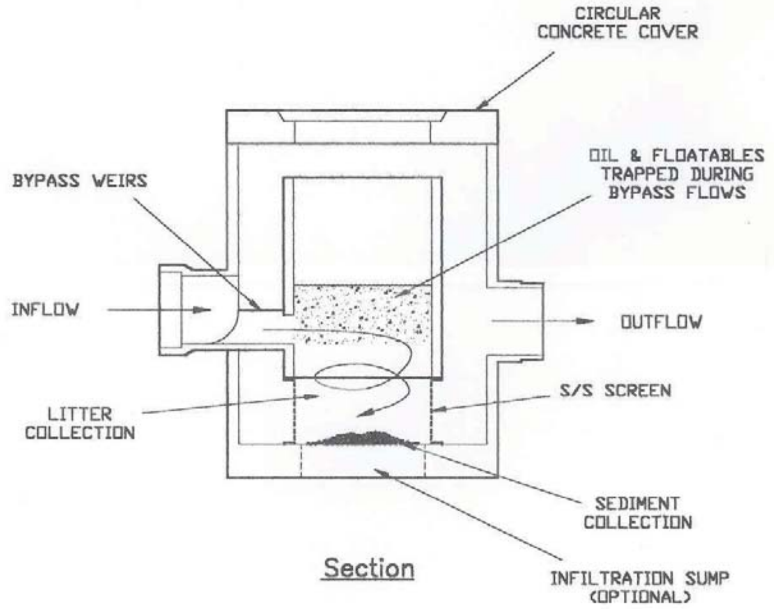
(From Rocla Literatures and web sites)

4. DRAWINGS AND DIMENSIONS

- Schematic drawing of VersaTrap® VT Series G
- Schematic drawing of VersaTrap® VT Series A
- Standard dimensions – VersaTrap® VT Series G
- Standard dimensions – VersaTrap® VT Series A
- Rocla VersaTrap® - Standard Minimum Dimensions
- Dimensioned drawing of VersaTrap® VT12/07G
- Dimensioned drawing of VersaTrap® VT12/07A
- Dimensioned drawing of VersaTrap® VT18/10G
- Dimensioned drawing of VersaTrap® VT18/10A



Plan

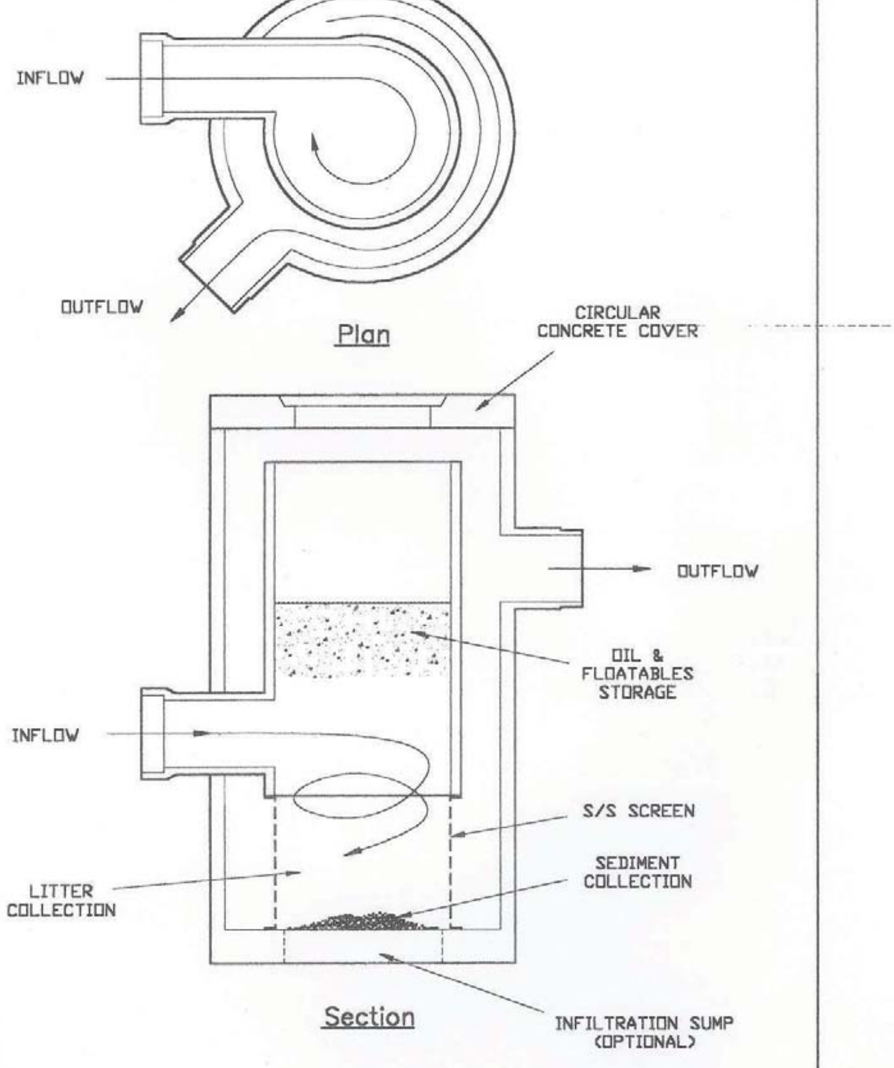


Section

VERSATRAP

Series G

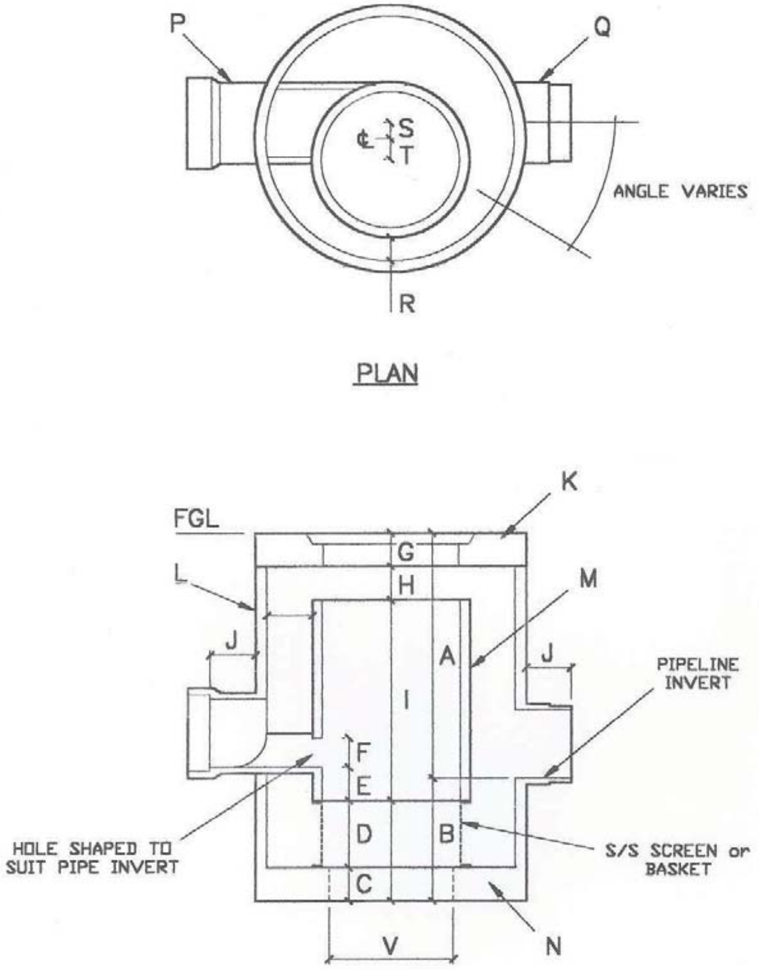
(N.T.S.)



VERSATRAP

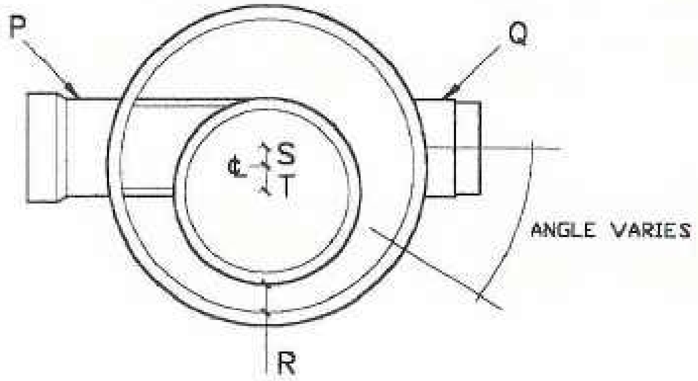
Series A

(N.T.S.)

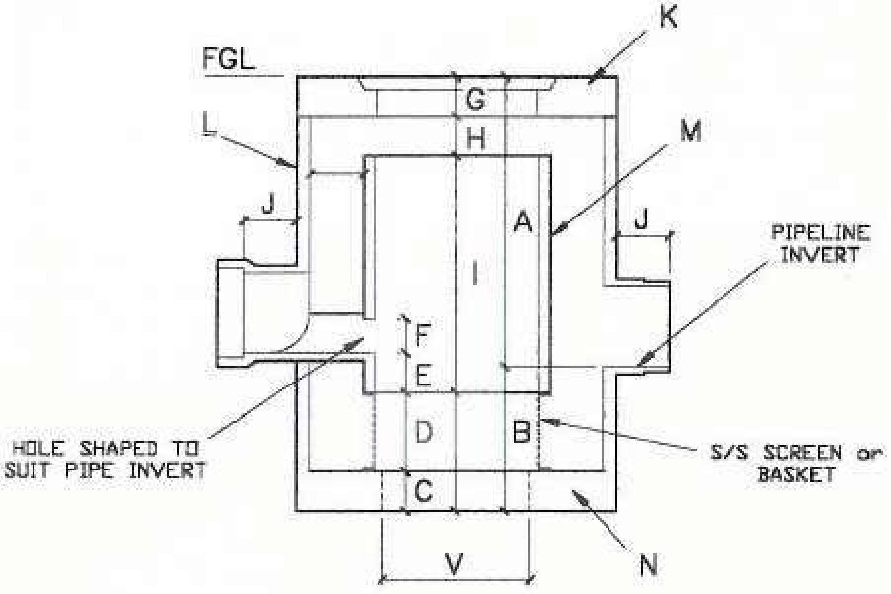


VERSA TRAP – SERIES G

DIMENSIONS

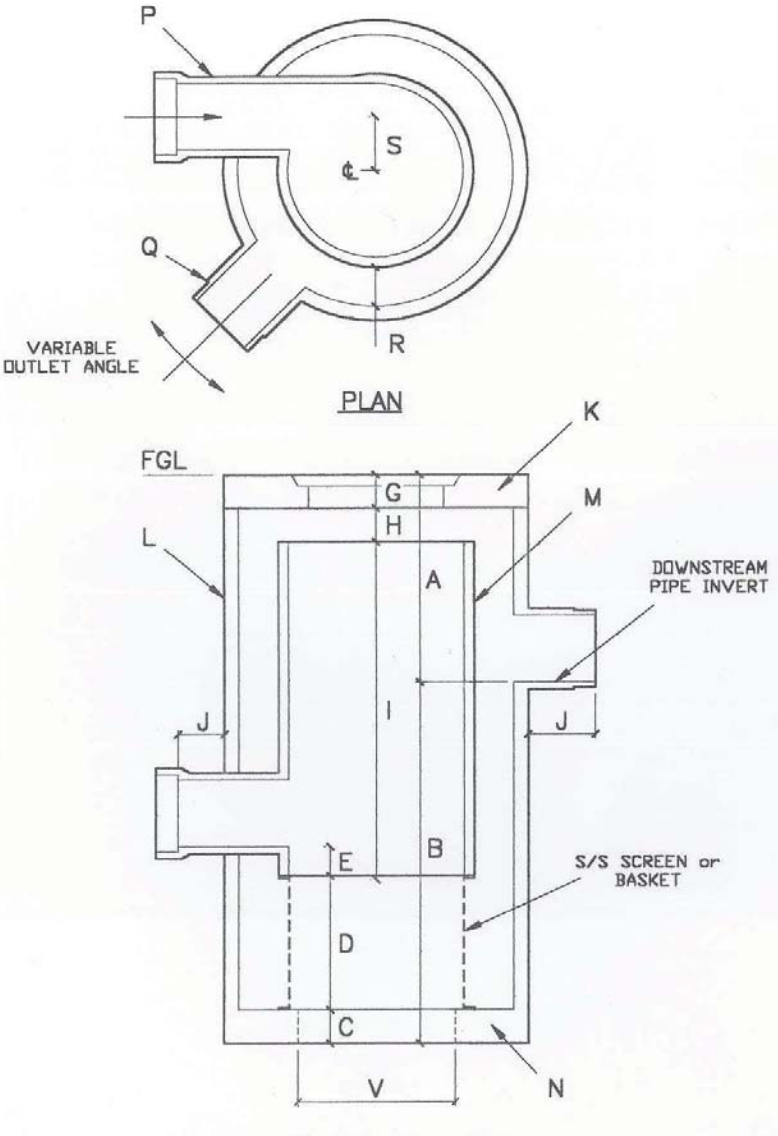


PLAN



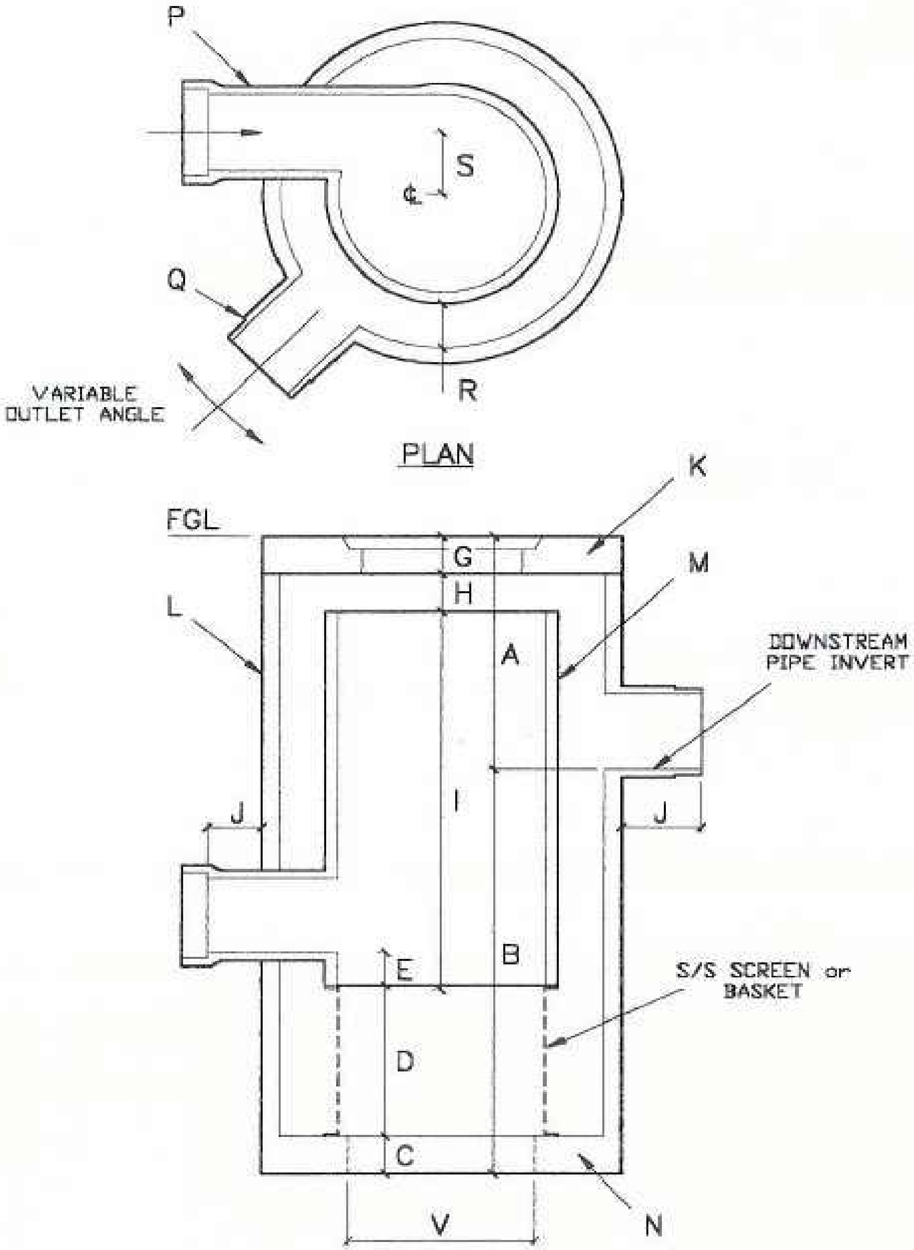
VERSA TRAP – SERIES G

DIMENSIONS



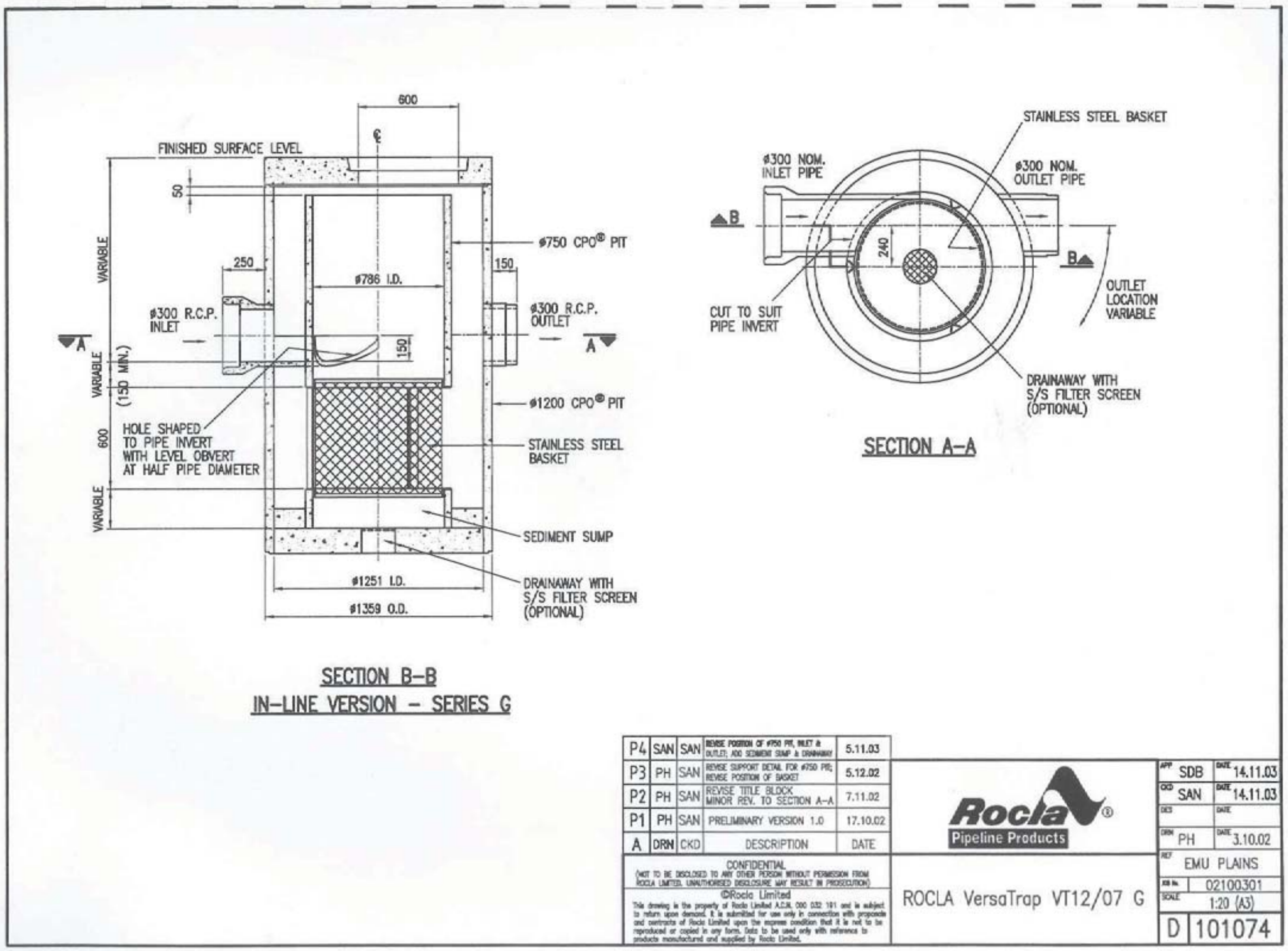
VERSA TRAP – SERIES A

DIMENSIONS



VERSA TRAP – SERIES A

DIMENSIONS

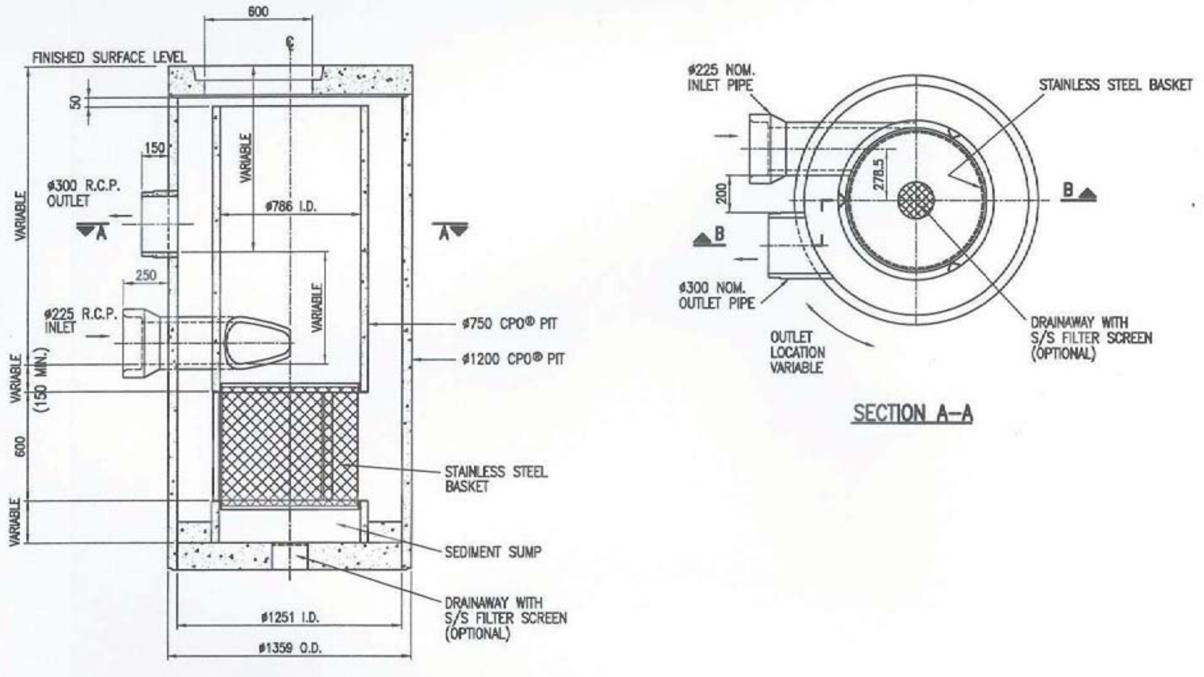


P4	SAN	SAN	REVISE POSITION OF ø750 PIT, INLET & OUTLET; ADD SEDIMENT SUMP & DRAINAWAY	5.11.03
P3	PH	SAN	REVISE SUPPORT DETAIL FOR ø750 PIT; REVISE POSITION OF BASKET	5.12.02
P2	PH	SAN	REVISE TITLE BLOCK MINOR REV. TO SECTION A–A	7.11.02
P1	PH	SAN	PRELIMINARY VERSION 1.0	17.10.02
A	DRN	CKD	DESCRIPTION	DATE

CONFIDENTIAL
(NOT TO BE DISCLOSED TO ANY OTHER PERSON WITHOUT PERMISSION FROM ROCLA LIMITED. UNAUTHORISED DISCLOSURE MAY RESULT IN PROSECUTION)

©Rocla Limited
This drawing is the property of Rocla Limited A.C.N. 000 032 191 and is subject to return upon demand. It is submitted for use only in connection with proposals and contracts of Rocla Limited upon the express condition that it is not to be reproduced or copied in any form. Data to be used only with reference to products manufactured and supplied by Rocla Limited.

ROCLA VersaTrap VT12/07 G



SECTION B-B
OFF-LINE VERSION – SERIES A

SECTION A-A

P4	SAN	SAN	REVISE POSITION OF ø750 PIT, INLET & OUTLET; ADD SEDIMENT SUMP & DRAINAWAY	5.11.03
P3	PH	SAN	REVISE INLET PIPE FROM ø300 TO ø225; REVISE SUPPORT DETAIL FOR ø750 PIPE	5.12.02
P2	PH	SAN	REVISE TITLE BLOCK MINOR REV. TO SECTION A–A	7.11.02
P1	PH	SAN	PRELIMINARY VERSION 1.0	17.10.02
A	DRN	CKD	DESCRIPTION	DATE

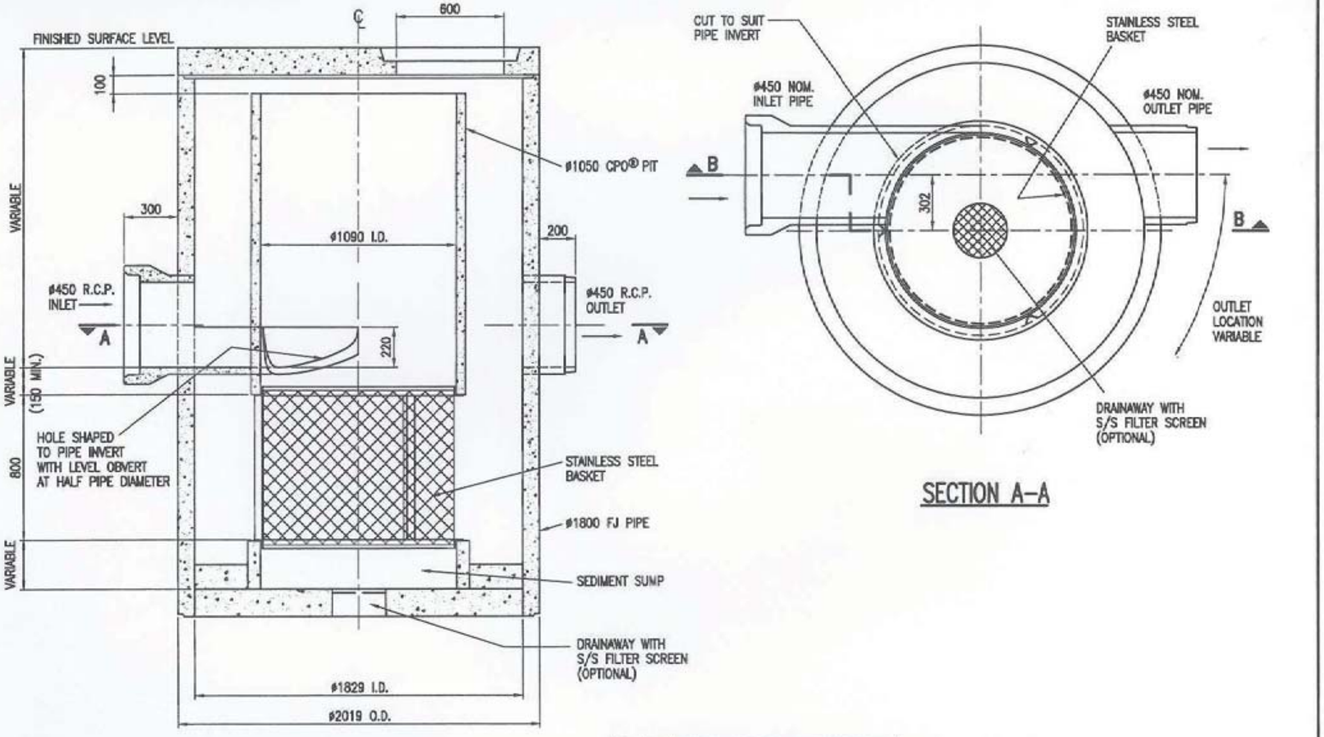
CONFIDENTIAL
(NOT TO BE DISCLOSED TO ANY OTHER PERSON WITHOUT PERMISSION FROM ROCLA LIMITED. UNAUTHORISED DISCLOSURE MAY RESULT IN PROSECUTION)

©Rocla Limited
This drawing is the property of Rocla Limited A.C.N. 000 032 191 and is subject to return upon demand. It is submitted for use only in connection with proposals and contracts of Rocla Limited upon the express condition that it is not to be reproduced or copied in any form. Data to be used only with reference to products manufactured and supplied by Rocla Limited.

Rocla®
Pipeline Products

ROCLA VersaTrap VT12/07 A

APP	SDB	DATE	14.11.03
CKD	SAN	DATE	14.11.03
DES		DATE	
DRN	PH	DATE	10.10.02
REF	EMU PLAINS		
JOB No.	02100301		
SCALE	1:20 (A3)		
D	101076		



SECTION B–B

IN–LINE VERSION SERIES G

P4	SAN	SAN	REVISE POSITION OF ø1050 PIT, INLET & OUTLET; ADD SEDIMENT SUMP & DRAINAWAY	04.11.02
P3	BS	SAN	REVISE SUPPORT DETAIL FOR ø1050 PIT; REVISE POSITION OF BASKET	06.12.02
P2	BS	SAN	REVISE TITLE BLOCK MINOR REV. TO SECTION A–A	07.11.02
P1	BS	SAN	PRELIMINARY VERSION 1.0	14.10.02
A	DRN	CKD	DESCRIPTION	DATE

CONFIDENTIAL
(NOT TO BE DISCLOSED TO ANY OTHER PERSON WITHOUT PERMISSION FROM ROCLA LIMITED. UNAUTHORISED DISCLOSURE MAY RESULT IN PROSECUTION)

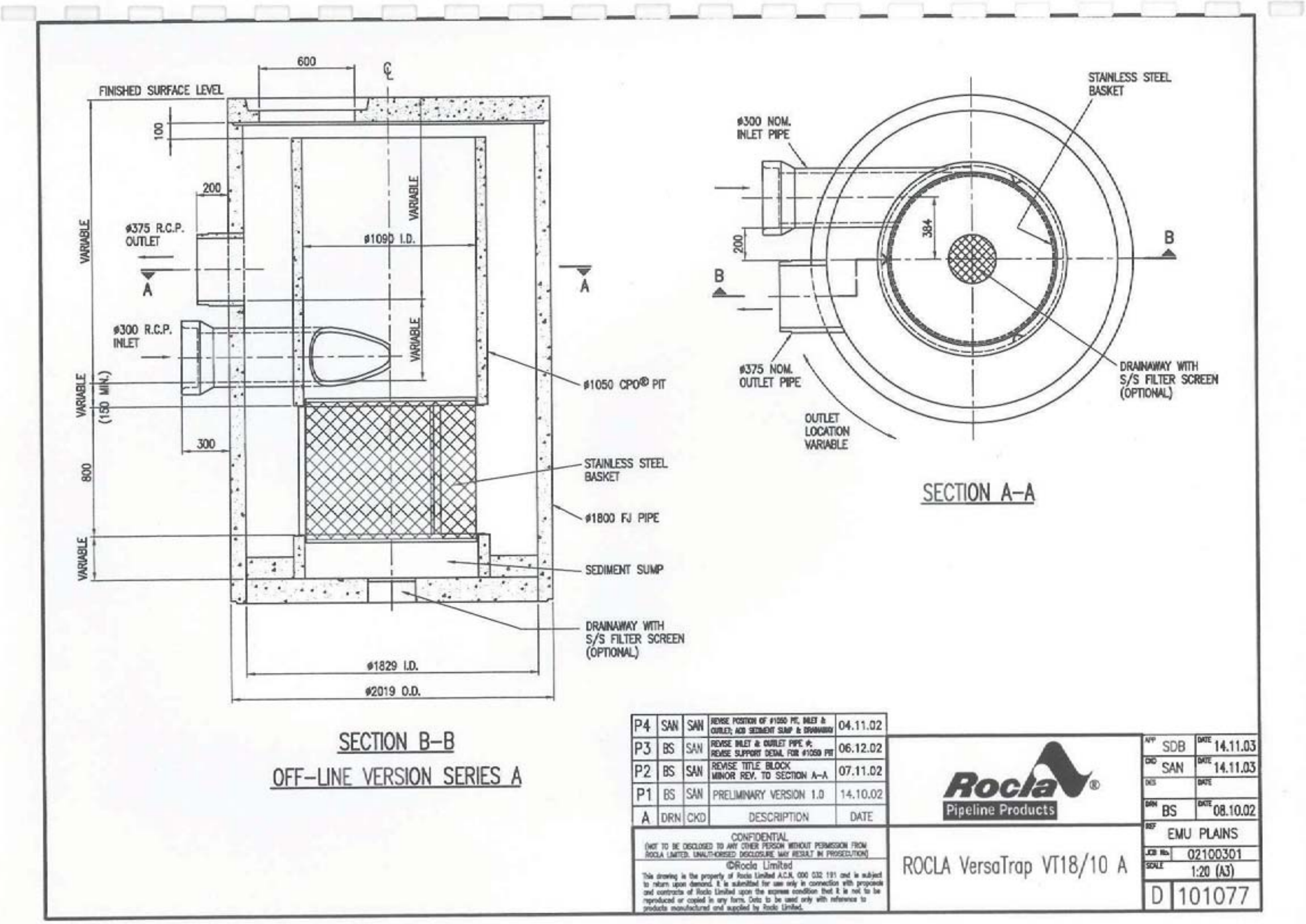
©Rocla Limited
This drawing is the property of Rocla Limited A.C.N. 000 032 191 and is subject to return upon demand. It is submitted for use only in connection with proposals and contracts of Rocla Limited upon the express condition that it is not to be reproduced or copied in any form. Data to be used only with reference to products manufactured and supplied by Rocla Limited.

Rocla® Pipeline Products

ROCLA VersaTrap VT18/10 G

APP	SDB	DATE	14.11.03
CKD	SAN	DATE	14.11.03
DCS		DATE	
DRN	BS	DATE	08.10.02

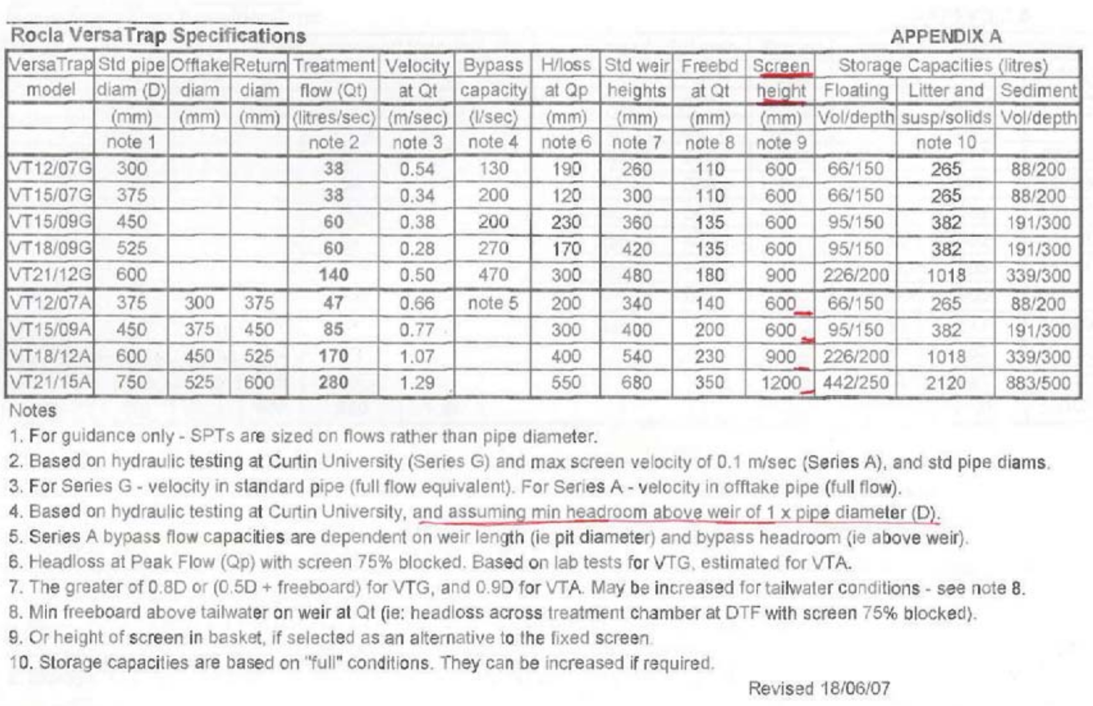
REF EMU PLAINS
JOB No. 02100301
SCALE 1:20 (A3)
D 101075


FINISHED SURFACE LEVEL
600
℄
100
200
VARIABLE
ø375 R.C.P. OUTLET
A
ø1090 I.D.
VARIABLE
VARIABLE
ø300 R.C.P. INLET
VARIABLE
(150 MIN.)
300
800
VARIABLE
ø1050 CPO® PIT
STAINLESS STEEL BASKET
ø1800 FJ PIPE
SEDIMENT SUMP
DRAINAWAY WITH S/S FILTER SCREEN (OPTIONAL)
ø1829 I.D.
ø2019 O.D.
SECTION B–B
OFF-LINE VERSION SERIES A
ø300 NOM. INLET PIPE
STAINLESS STEEL BASKET
384
200
B
B
ø375 NOM. OUTLET PIPE
OUTLET LOCATION VARIABLE
DRAINAWAY WITH S/S FILTER SCREEN (OPTIONAL)
SECTION A–A
P4 SAN SAN REVISE POSITION OF ø1050 PIT, INLET & OUTLET; ADD SEDIMENT SUMP & DRAINAWAY 04.11.02
P3 BS SAN REVISE INLET & OUTLET PIPE ø; REVISE SUPPORT DETAIL FOR ø1050 PIT 06.12.02
P2 BS SAN REVISE TITLE BLOCK MINOR REV. TO SECTION A–A 07.11.02
P1 BS SAN PRELIMINARY VERSION 1.0 14.10.02
A DRN CKD DESCRIPTION DATE
CONFIDENTIAL
(NOT TO BE DISCLOSED TO ANY OTHER PERSON WITHOUT PERMISSION FROM ROCLA LIMITED. UNAUTHORISED DISCLOSURE MAY RESULT IN PROSECUTION)
©Rocla Limited
This drawing is the property of Rocla Limited A.C.N. 000 032 191 and is subject to return upon demand. It is submitted for use only in connection with proposals and contracts of Rocla Limited upon the express condition that it is not to be reproduced or copied in any form. Data to be used only with reference to products manufactured and supplied by Rocla Limited.
Rocla®
Pipeline Products
ROCLA VersaTrap VT18/10 A
APP SDB DATE 14.11.03
CKD SAN DATE 14.11.03
DES DATE
DRN BS DATE 08.10.02
REF EMU PLAINS
JOB No. 02100301
SCALE 1:20 (A3)
D 101077

Rocla VersaTrap SPT - Standard Minimum Dimensions

MODEL	A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	Q	R	S, T	V
Note no	1	2&3		4		5	6	7	8		9	nom/OD	nom/OD	10	11		min	12	13
12/07G		900	150	400	150		150 typ	5 typ		150		1200/1359	750/862	base	300	300	100		300
15/09G		1200	150	600	150		150 typ	5 typ		200		1500/1689	900/1029	"	375	375	100		300
21/12G		1500	200	800	150		200 typ	5 typ		250		1800/2019	1200/1359	"	450	450	150		300
12/07A		900	150	400	150		150 typ	5 typ		150		1200/1359	750/862	"	300	300	100		300
15/09A		1200	150	600	150		150 typ	5 typ		200		1500/1689	900/1029	"	375	375	100		300
18/12A		1500	150	800	150		150 typ	5 typ		250		1800/2019	1200/1359	"	450	450	150		300
21/15A		1900	200	1200	200		200 typ	5 typ		300		2100/2336	1500/1689	"	600	600	150		300

note 1 varies according to depth of pipeline.
note 2 cross-fall is nominally 50mm in series G units, but may be adjusted to suit specific flows or site situations.
note 3 inlet level in Series A (offline) units may be varied to suit floatables collection efficiency and storage capacity requirements.
note 4 screen/basket depth may be varied to suit storage capacity requirements.
note 5 varies according to pipe diameter and tailwater level
note 6 varies depending on cover type.
note 7 varies depending on depth of pipeline, upstream conditions, surcharge potential, etc.
note 8 equals A+B-C-D-G-H. Try To use standard lengths.
note 9 type of cover varies according to cover type and load capacity, etc.
note 10 generally internal, but flanged base required in high water table conditions, to prevent uplift.
note 11 typical for Series G only
note 12 varies depending on pipe diameter, change of angle, etc
note 13 where exfiltration is required, to drain the storage chamber, a 300 diam hole with stainless steel screen is provided.



Rocla VersaTrap Specifications

APPENDIX A

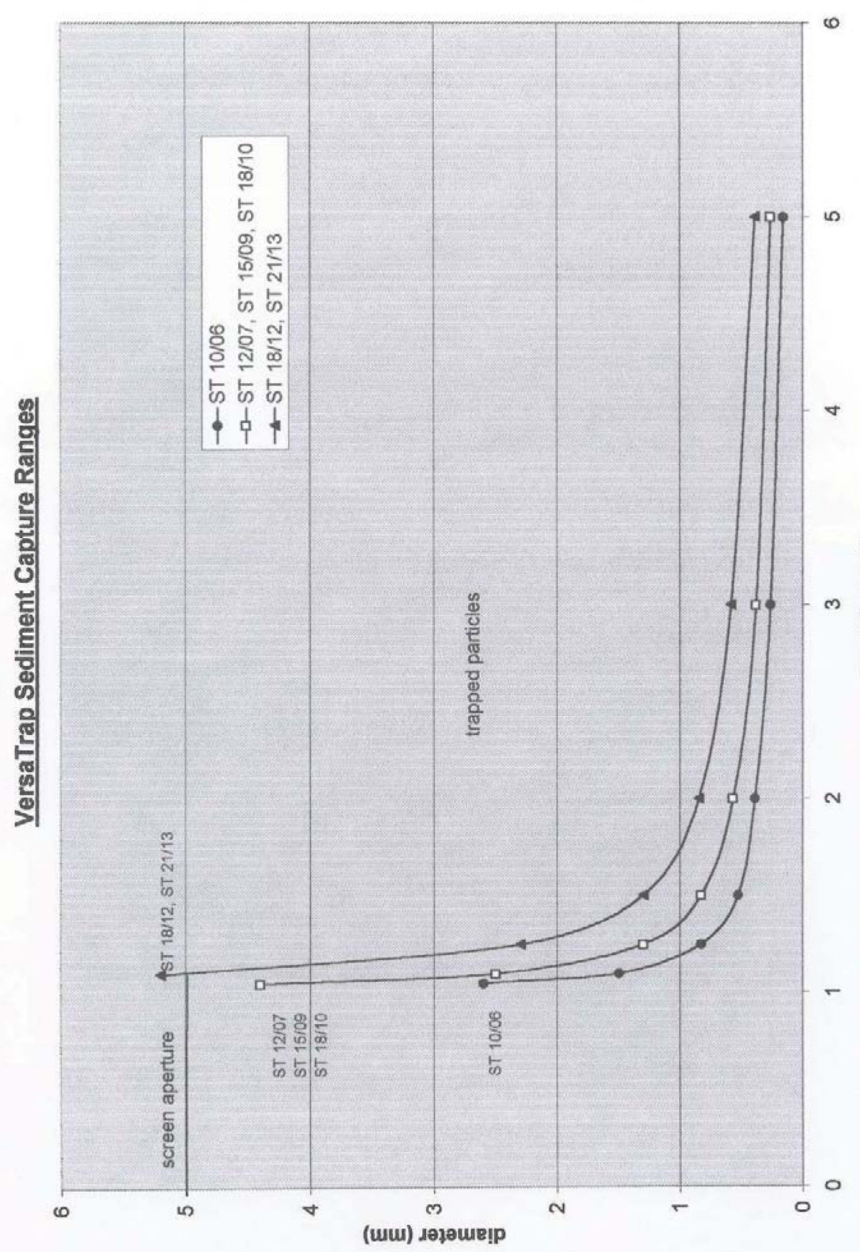
VersaTrap	Std pipe	Offtake	Return	Treatment	Velocity	Bypass	H/loss	Std weir	Freebd	Screen	Storage Capacities (litres)		
model	diam (D)	diam	diam	flow (Qt)	at Qt	capacity	at Qp	heights	at Qt	height	Floating	Litter and	Sediment
	(mm)	(mm)	(mm)	(litres/sec)	(m/sec)	(l/sec)	(mm)	(mm)	(mm)	(mm)	Vol/depth	susp/solids	Vol/depth
	note 1			note 2	note 3	note 4	note 6	note 7	note 8	note 9		note 10	
VT12/07G	300			38	0.54	130	190	260	110	600	66/150	265	88/200
VT15/07G	375			38	0.34	200	120	300	110	600	66/150	265	88/200
VT15/09G	450			60	0.38	200	230	360	135	600	95/150	382	191/300
VT18/09G	525			60	0.28	270	170	420	135	600	95/150	382	191/300
VT21/12G	600			140	0.50	470	300	480	180	900	226/200	1018	339/300
VT12/07A	375	300	375	47	0.66	note 5	200	340	140	600	66/150	265	88/200
VT15/09A	450	375	450	85	0.77		300	400	200	600	95/150	382	191/300
VT18/12A	600	450	525	170	1.07		400	540	230	900	226/200	1018	339/300
VT21/15A	750	525	600	280	1.29		550	680	350	1200	442/250	2120	883/500

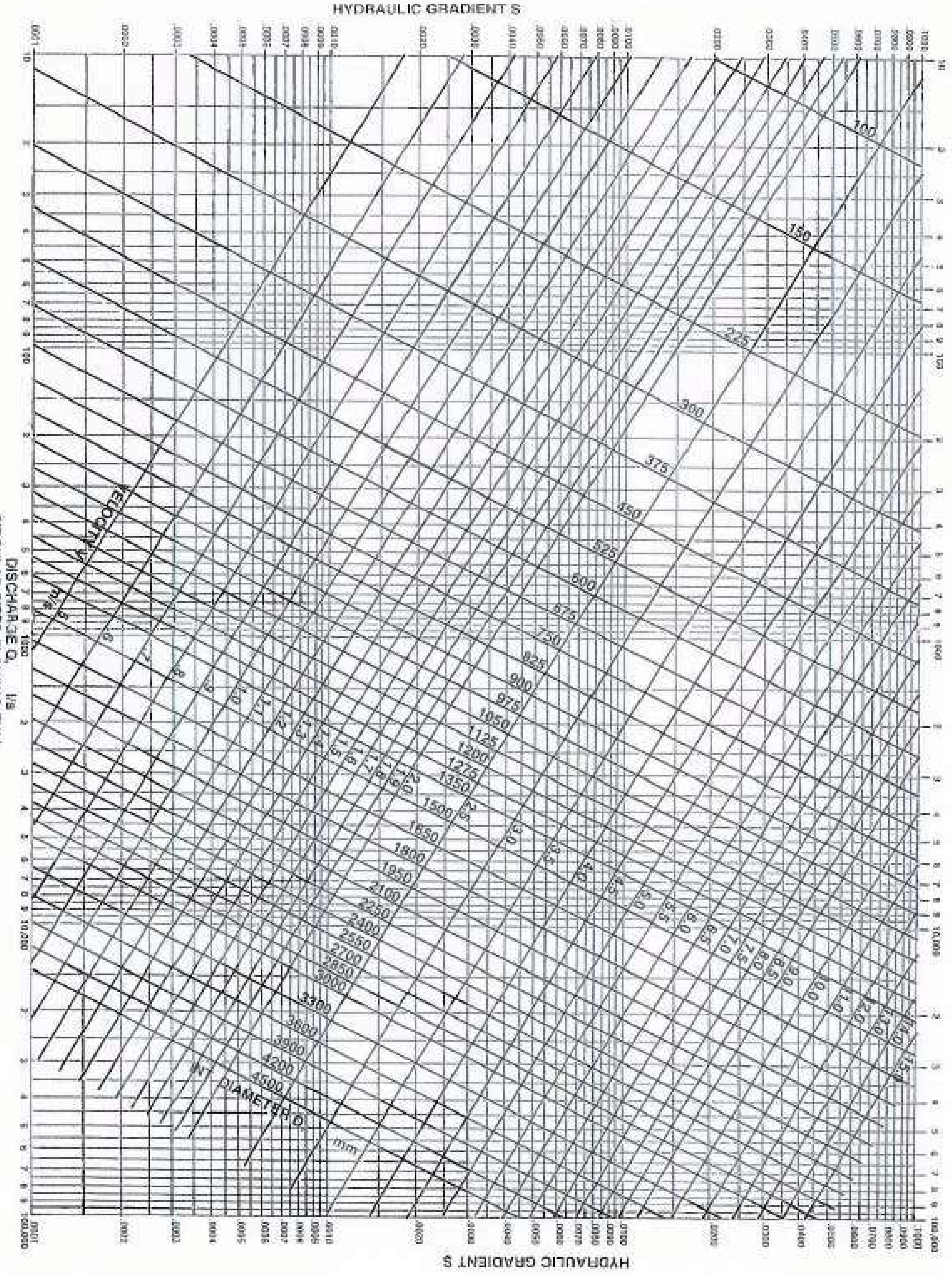
Notes

1. For guidance only - SPTs are sized on flows rather than pipe diameter.
2. Based on hydraulic testing at Curtin University (Series G) and max screen velocity of 0.1 m/sec (Series A), and std pipe diams.
3. For Series G - velocity in standard pipe (full flow equivalent). For Series A - velocity in offtake pipe (full flow).
4. Based on hydraulic testing at Curtin University, and assuming min headroom above weir of 1 x pipe diameter (D).
5. Series A bypass flow capacities are dependent on weir length (ie pit diameter) and bypass headroom (ie above weir).
6. Headloss at Peak Flow (Qp) with screen 75% blocked. Based on lab tests for VTG, estimated for VTA.
7. The greater of 0.8D or (0.5D + freeboard) for VTG, and 0.9D for VTA. May be increased for tailwater conditions - see note 8.
8. Min freeboard above tailwater on weir at Qt (ie: headloss across treatment chamber at DTF with screen 75% blocked).
9. Or height of screen in basket, if selected as an alternative to the fixed screen.
10. Storage capacities are based on "full" conditions. They can be increased if required.

Revised 18/06/07

Sediment Collection Performance Chart **APPENDIX D**



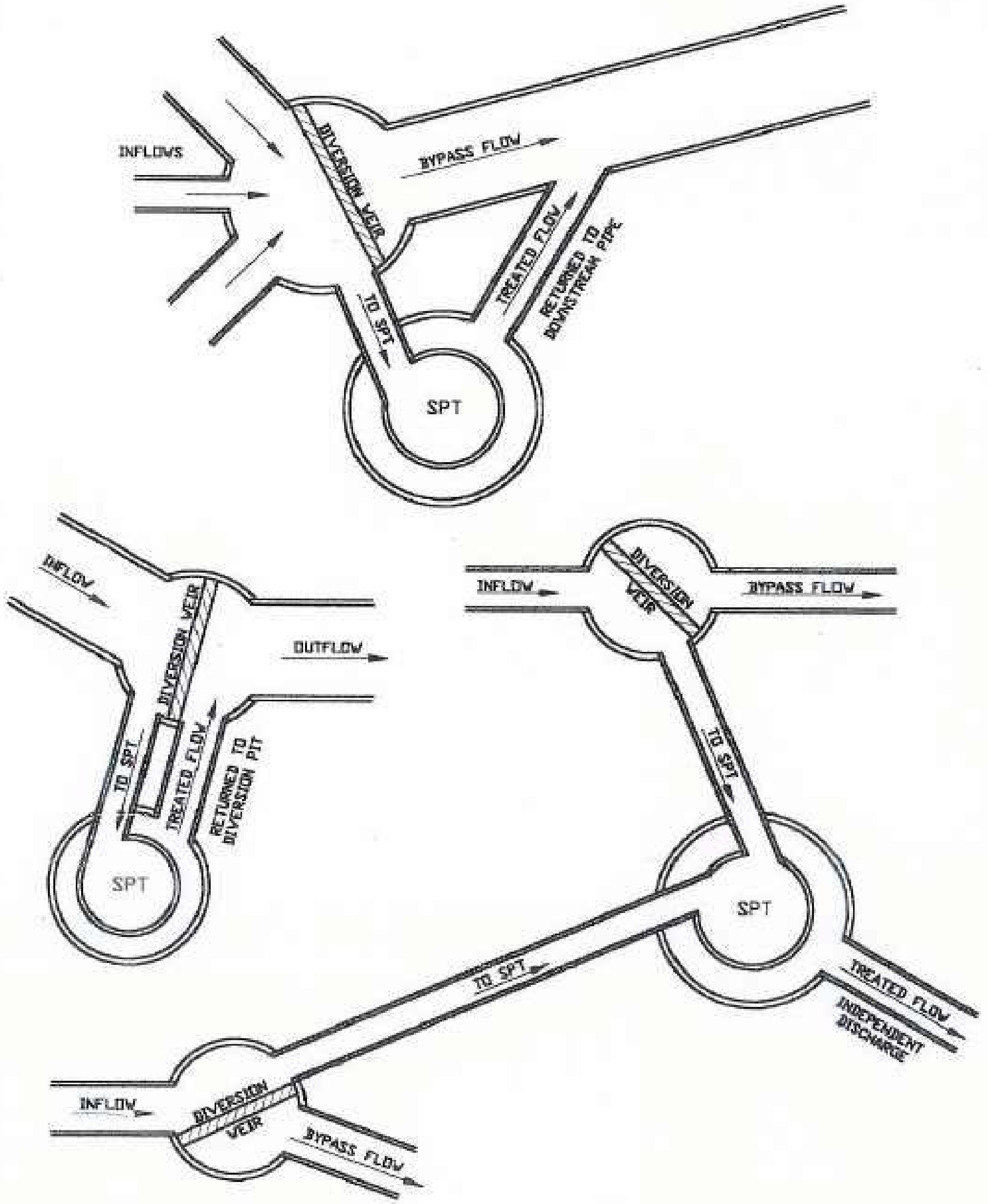


DISCHARGE Q l/s

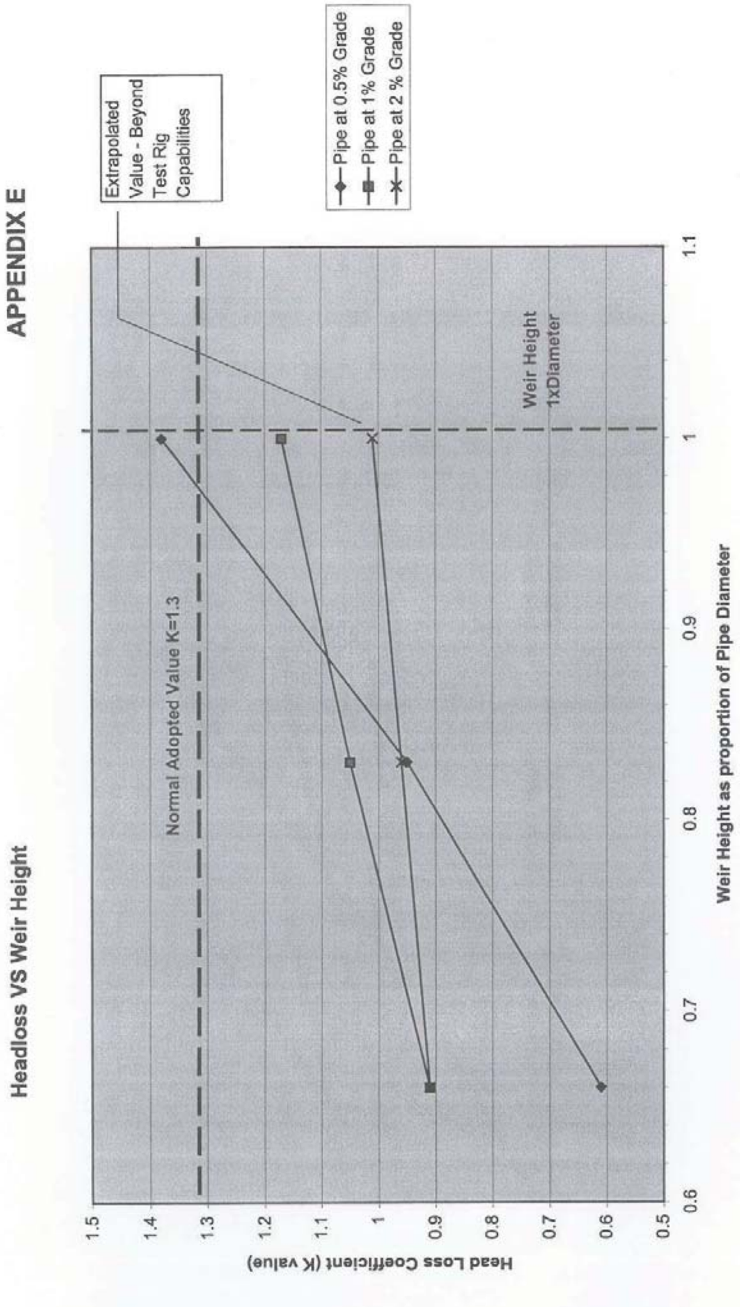
CIRCULAR PIPES FLOWING FULL

COLEBROOK-WHITE FORMULA k = 0.15mm

Typical Layouts for Offline SPT's (Series A)

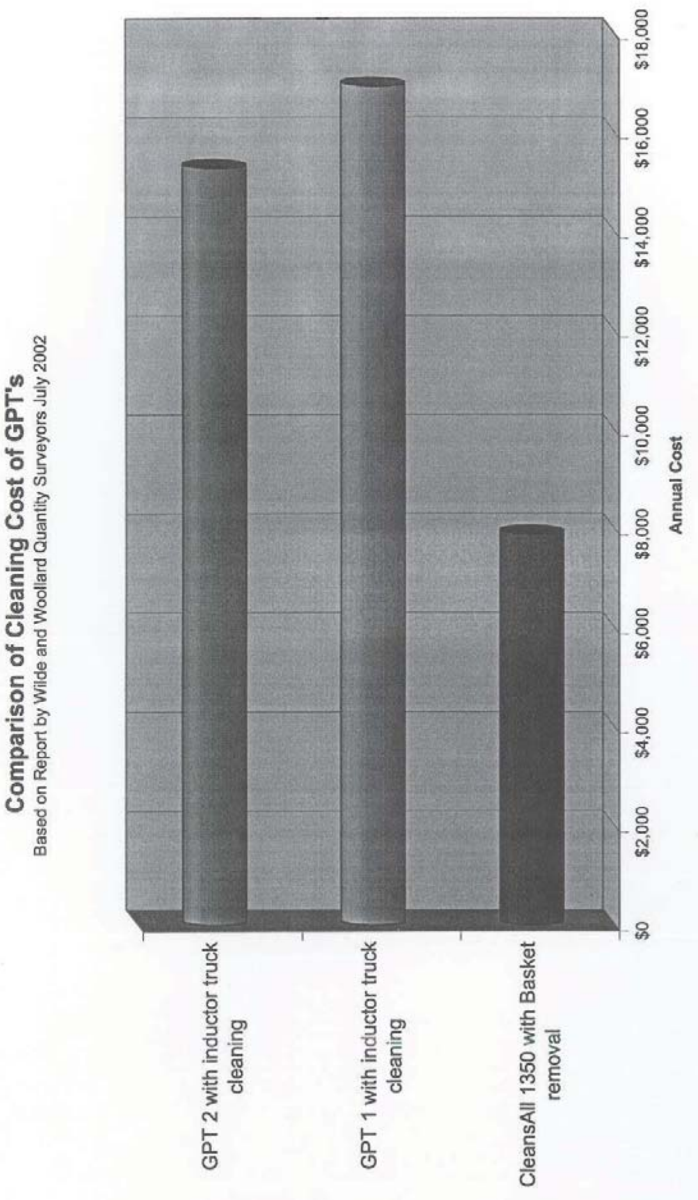


Headloss versus Weir Height **APPENDIX E**



Comparison of Maintenance Costs
(basket versus vacuum eduction)

APPENDIX H



Comparison of Cleaning Cost of GPT's

Based on Report by Wilde and Woollard Quantity Surveyors July 2002

APPENDIX (C)

EXPERIMENTAL RESULTS APPENDIX

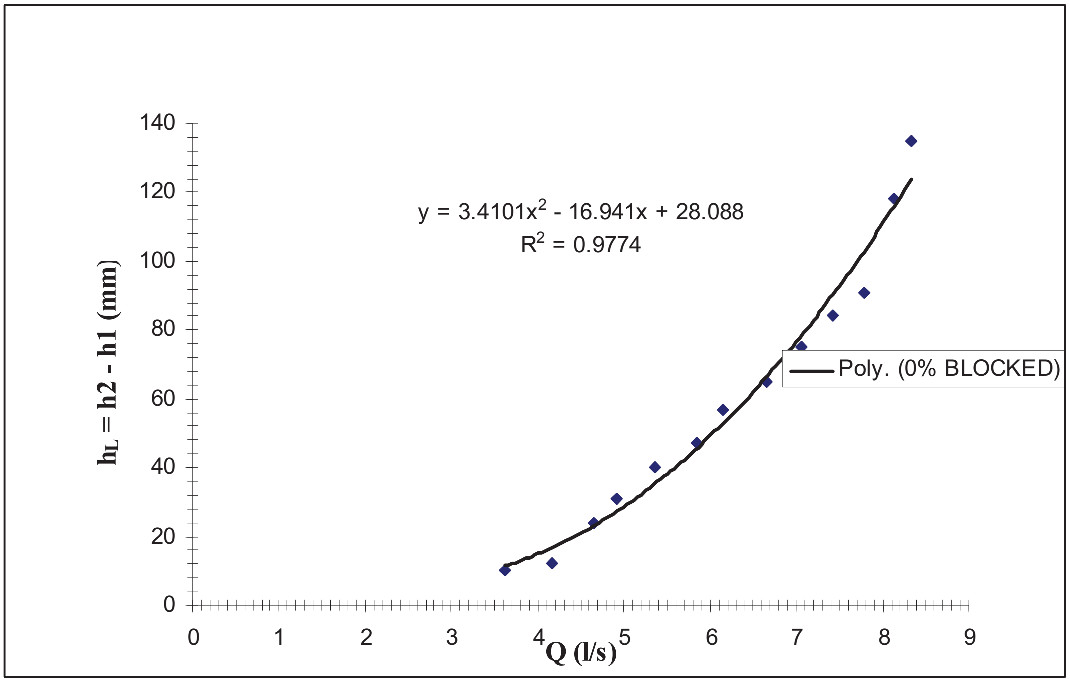


Figure 1, Flow Vs Headloss at 0% Blocked Condition

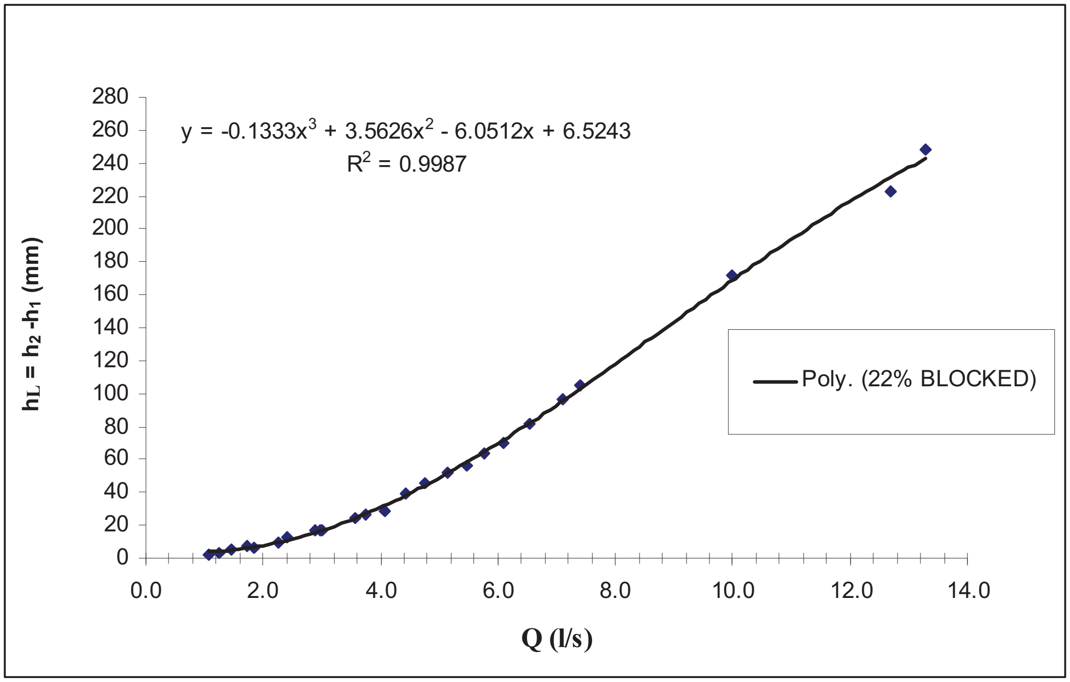


Figure 2, Flow Vs Headloss at 22 % Blocked Condition

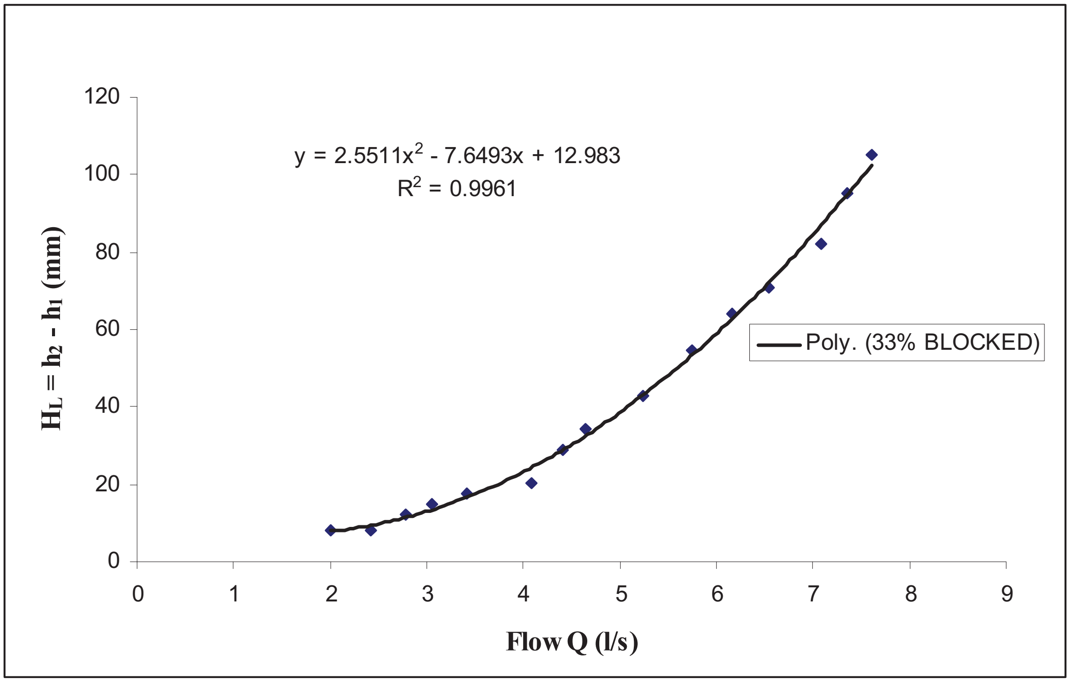


Figure 3, Flow Vs Headloss at 33 % Blocked Condition

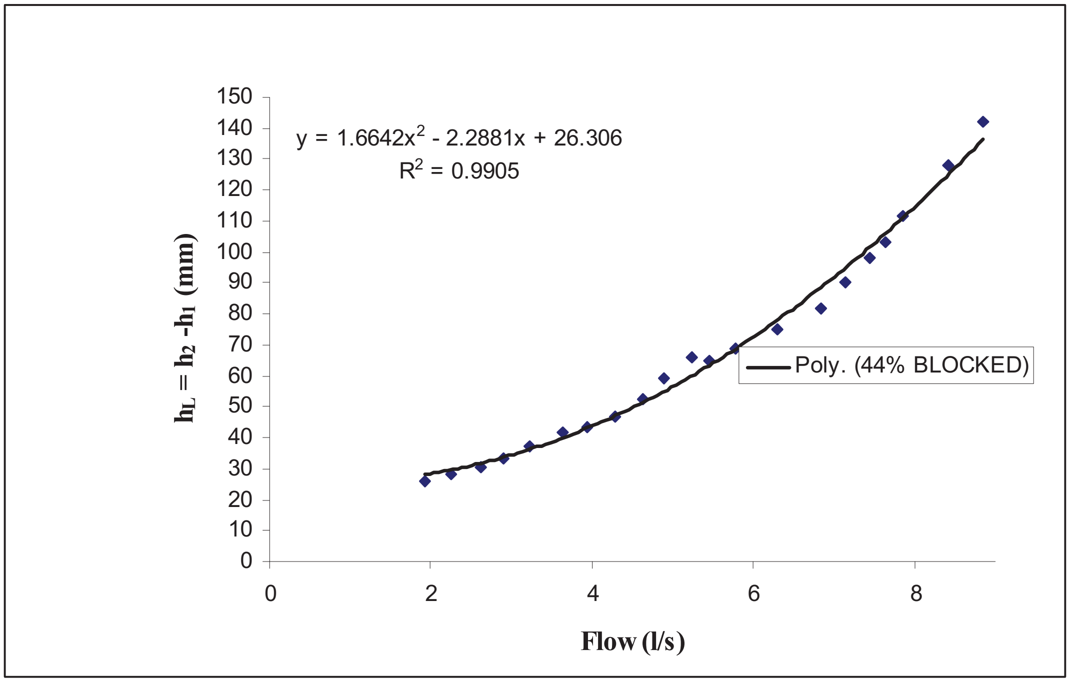


Figure 4, Flow Vs Headloss at 44 % Blocked Condition

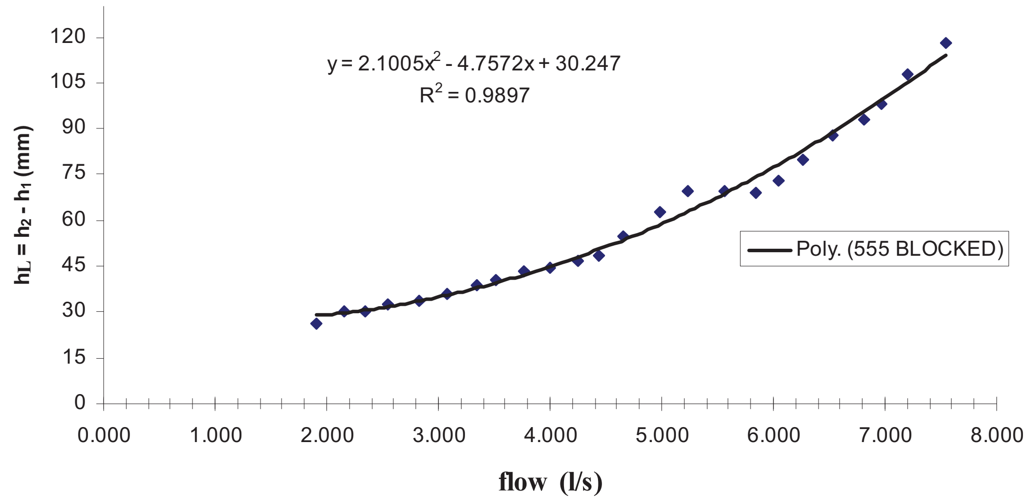


Figure 5, Flow Vs Headloss at 55 % Blocked Condition

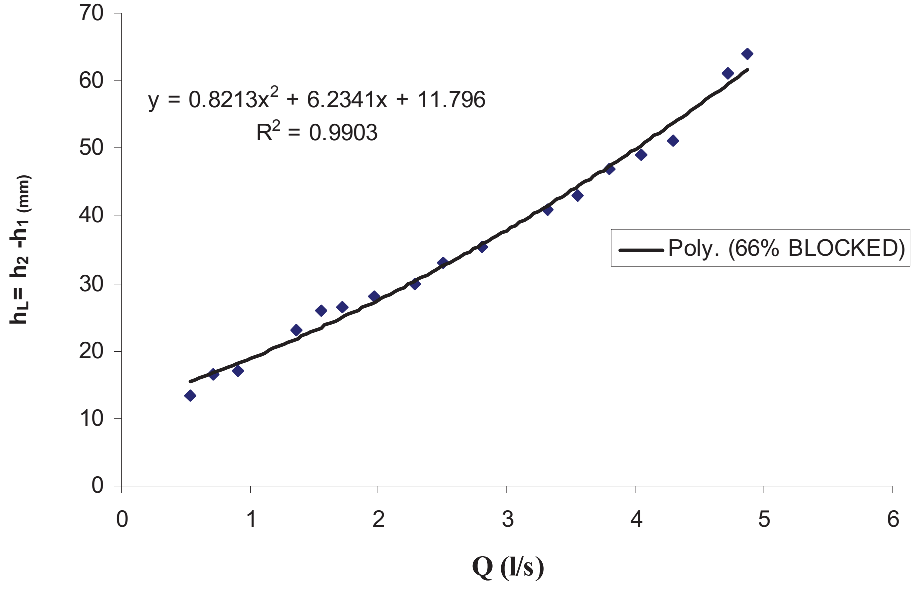


Figure 6, Flow Vs Headloss at 66 % Blocked Condition

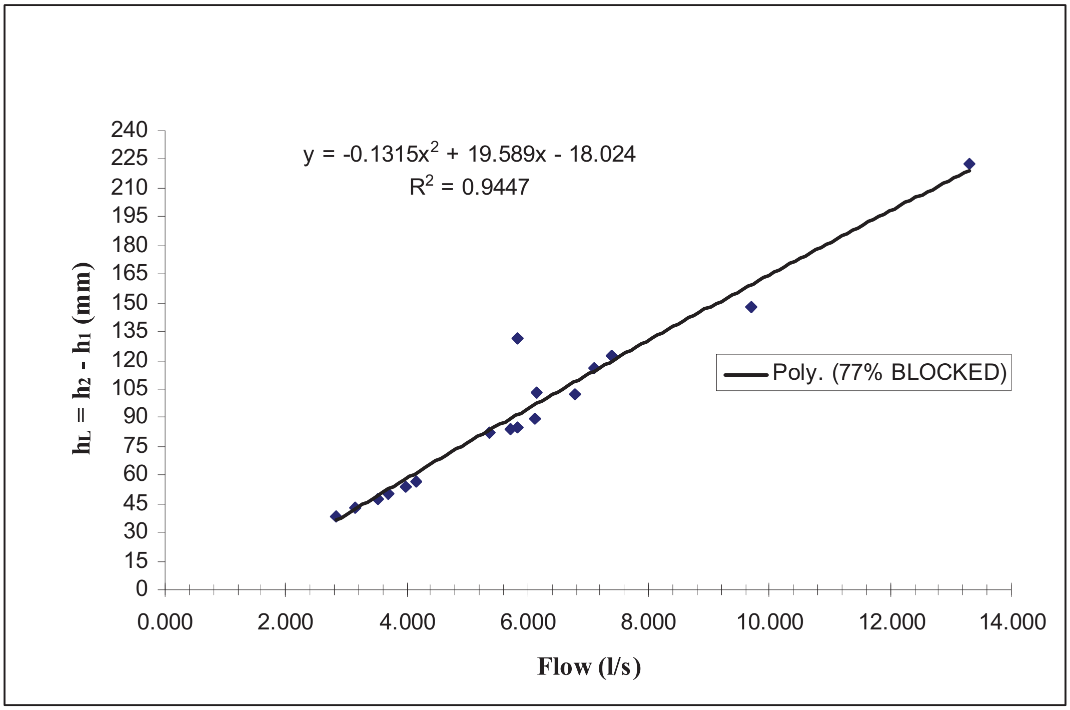


Figure 7, Flow Vs Headloss at 77 % Blocked Condition

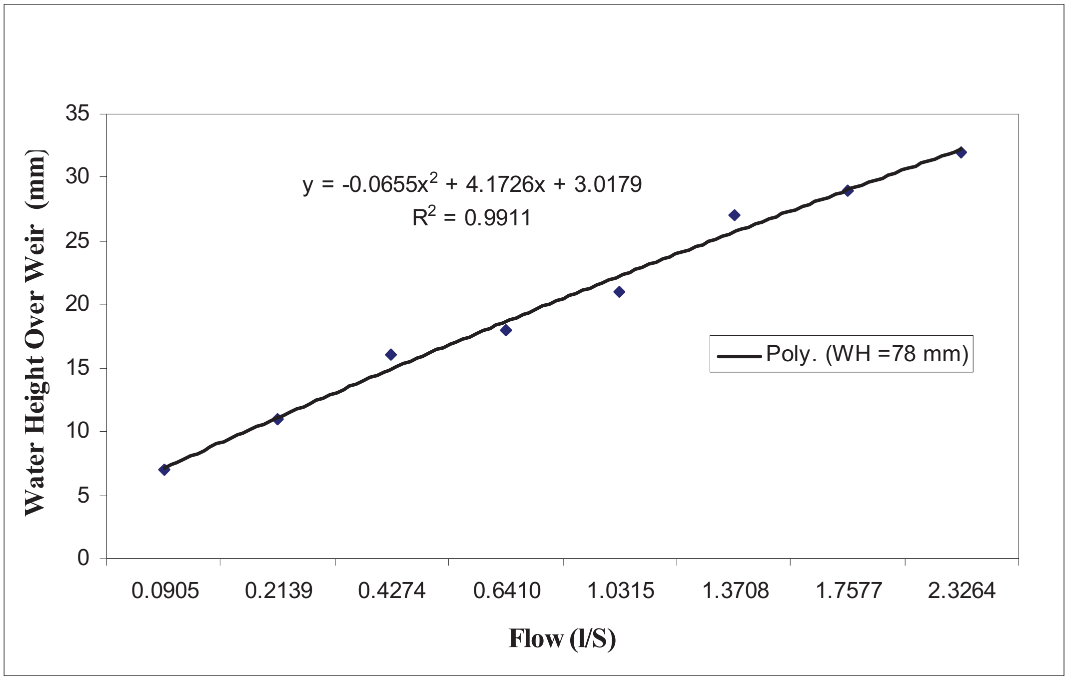


Figure 8, Flow Vs Water Height over Weir (78 mm)

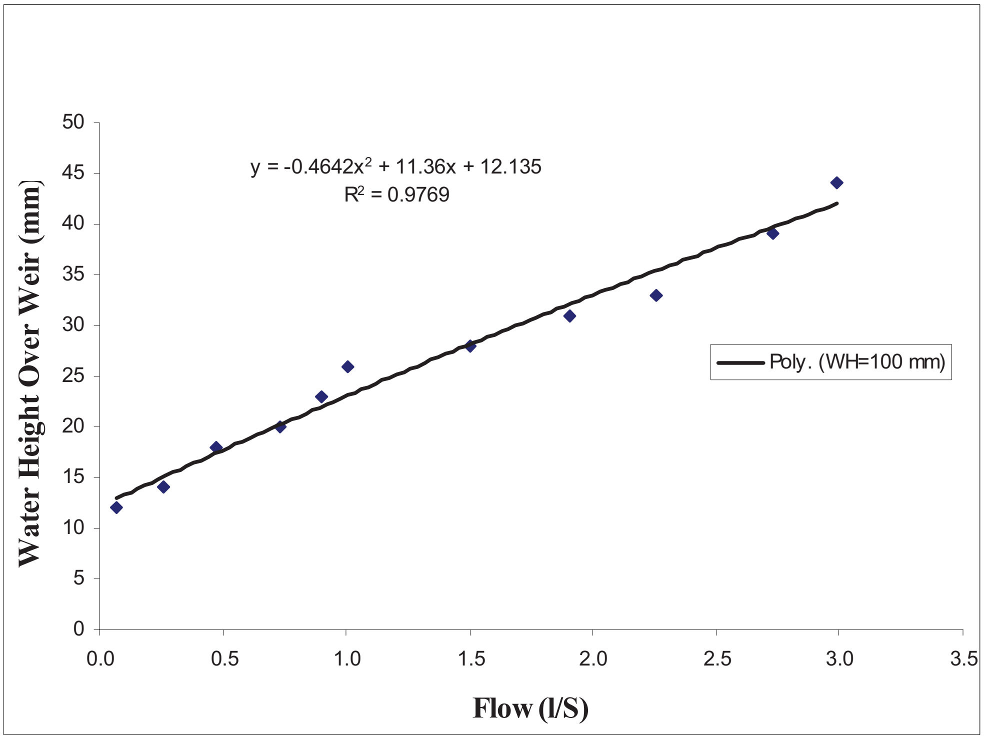


Figure 9, Flow Vs Water Height over Weir (100 mm)

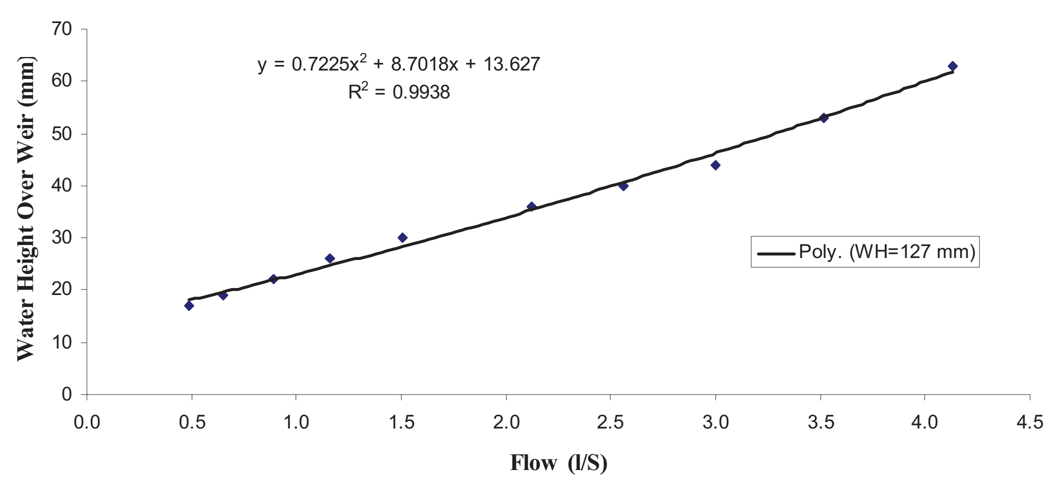


Figure 10, Flow Vs Water Height over Weir (127 mm)

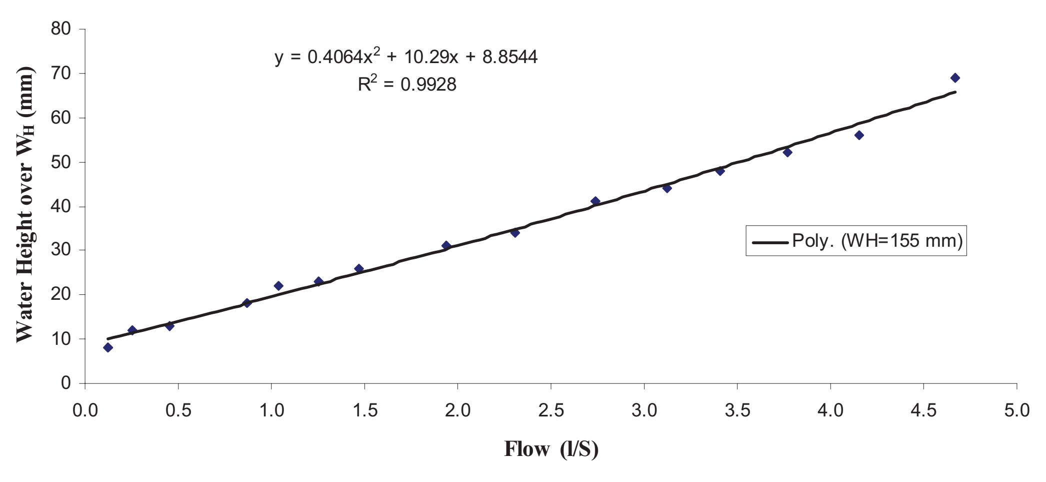


Figure 11, Flow Vs Water Height over Weir (155 mm)

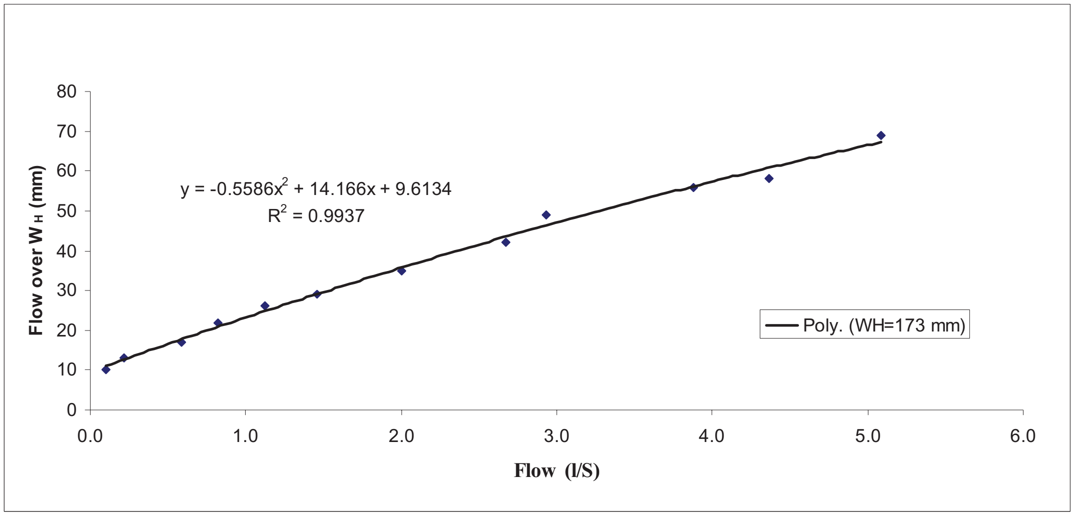


Figure 12, Flow Vs Water Height over Weir (173 mm)

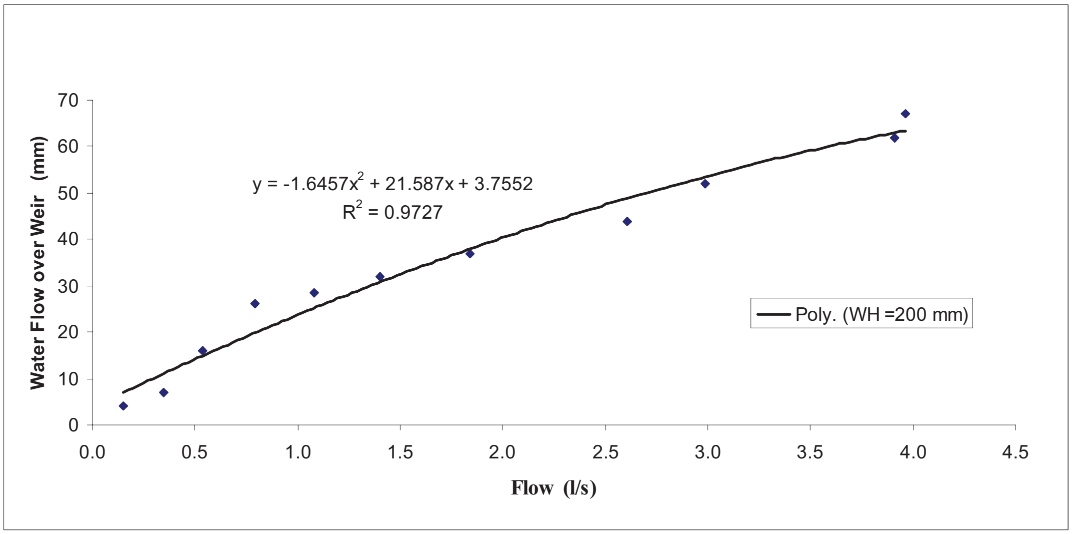


Figure 13, Flow Vs Water Height over Weir (200 mm)

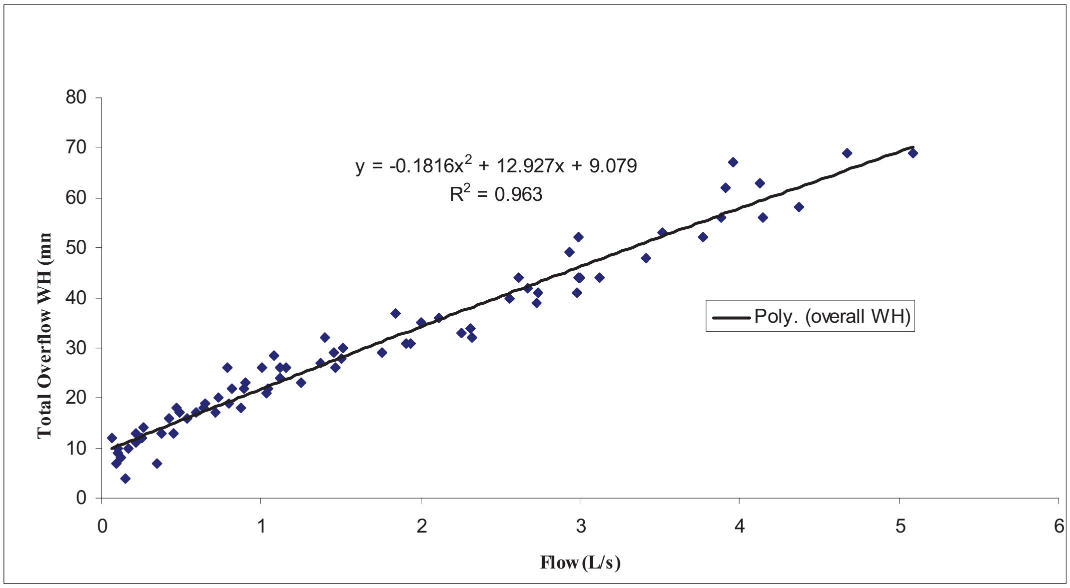


Figure 14, Flow Vs Total Water Over Weir Flow

APPENDIX (D)

WETLAND CLASSIFICATION

REVIEW OF WETLAND CLASSIFICATION (COLLECTED FROM DIFFERENT SOURCES)

Goodrick (1970) used water type (saline or fresh), permanence, depth and vegetation types to classify coastal wetlands of New South Wales. Goodrick has also ranked the value of each wetland type as waterfowl habitat, therefore making it useful for wildlife management.

DWR (1990) groups wetlands firstly by geomorphic origin and secondly by morphology. The focus of the classification is on morphology rather than hydrology and hence wetlands in different systems and sub-systems have similar management potential and threats. The proposed classification derives some wetland types from this classification.

Corrick and Norman (1980) used water type, depth and permanence as primary criteria with further sub-divisions based on vegetation type. It also includes two man-made wetland types (sewage ponds and salt works). Sub-categories of vegetation used to describe freshwater wetlands are not exclusive to the main wetland categories, and hence from a management perspective there would appear to be some overlap.

Paijmans et al. (1985) groups wetlands into major geomorphic types and then sub-divides these types on the basis of frequency of inundation. Groups can be further sub-divided by vegetation type. Whilst the major geomorphic divisions form clear wetland types, the hydrologic sub-divisions are too finely divided to enable the application of the broad management guidelines which will be developed in the manual. Green et al (1992) trailed this classification using wetland data from the Gwydir Valley. The classification resulted in wetland types with different water management potentials, and hence it was concluded that it was not particularly useful from the perspective of water management.

Jacobs (1983) uses a loose geographic and geomorphic wetland classification, which was designed for the description of wetland vegetation. There is similarity between the coastal and tableland wetland types used by Jacobs and those proposed in this paper, however Jacobs' inland wetland types do not incorporate any hydrologic criteria, which is a critical issue in the management of these wetlands.

Cowling (1977) uses geographic location (inland or coastal) and water type (saline or fresh) as the major criteria for classifying wetlands. Wetland types are further divided by a variety of criteria including hydrology (frequency of flooding, depth), morphology and vegetation type. The first level of classification only results in four wetlands type and is far too broad to apply management guidelines, and the next level is too finely divided. The classification was developed with the purpose of classifying waterbird habitat.

The RAMSAR classification is adopted as the official classification for the Directory of Important Wetlands in Australia. This classification includes man-made wetlands (water storages, ponds, gravel pits, irrigation channels etc) and marine wetlands (reefs, beaches etc) which are not relevant to the guidelines being prepared. Of the remaining categories, wetlands are divided according to hydrologic regime, size and geomorphology although there is no set structure to the classes.

Briggs (1981) developed a vegetation classification for freshwater wetlands. The classification is useful in a botanical sense but management principles for many of the different wetland types would be similar (for example there would be no difference in the management of a swamp forest to a swamp woodland of the same species).

Beadle (1981) classified wetlands according to vegetation alliances. As the classification is Australia - wide many of the vegetation types are not relevant to New South Wales wetlands.

In addition, the level of classification (down to dominant species) is beyond the broad management guidelines intended for the manual.

Semeniuk (1987) was developed for Western Australian wetlands and is a non-hierarchical system based on the primary criteria of water permanence and the cross-sectional shape of the wetland. Descriptors may be attached to the seven main wetland types to describe salinity, shape and size of the wetland. Green et al. (1992) trailed the classification on wetland data for the Gwydir valley and concluded that in terms of water management the scheme was not particularly useful in separating wetlands according to management potential as the classification does not give any indication of a wetlands position in the landscape, only its cross-sectional shape. It also does not include estuarine wetlands.

Cowardin et al (1979) is the official wetland classification of the United States Fish and Wildlife Service. The system is hierarchical, progressing from five major systems through to subsystems, classes and subclasses. The main criteria are geomorphic origin, broad hydrology and substrate type. Green et al. (1992) trailed this classification on wetlands in the Gwydir Valley and found that the classification resulted in too many wetland groups, some of which were not significantly different from others. It was also dependent on some threshold values for wetland size and vegetation cover, which have questionable value for management purposes.

Winning (1992) uses morphology and hydrology as the primary criteria for describing wetlands. Winnings classification is based on 15 morphological classes which may then be divided into various sub-classes according to hydrology or specific morphologic characteristics. River and creek channels were deemed to be outside of the scope of the technical manual and hence Winning's four morphological classes relating to channels are not appropriate for this study. The remaining classes however are useful for broadly dividing wetland types according to their location within the landscape and broad water source, characteristics, which are useful from a water management perspective. Some of Winning's wetland types are similar to those of DWR (1990) and have been used in the proposed classification.